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THE CHEMICAL NATURE OF SOME TYPICAL SOIL PROFILES OF SASKATCHEWAN, CANADA

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The morphology of the more important soils found in the Province of Saskatchewan has been described by Joel (7) and in Saskatchewan Soil Survey Report No. 10 (15). Type profiles were described and discussed in some detail in the above publications, as was also the relationship of these soils to world soil groups.

The purpose of this paper is to present chemical data for typical profiles representing the main soil groups found in Saskatchewan. This paper is therefore supplemental to the above mentioned publication by Joel and the reader is referred to it for more detailed morphological descriptions of soil profiles as well as a more detailed discussion of the climatic and vegetational conditions found in Saskatchewan.

A sketch map of part of the Province (Figure 1) shows the location of the main soil zones and also gives the approximate location where the profiles discussed in this paper were obtained. The numbers given on the sketch map

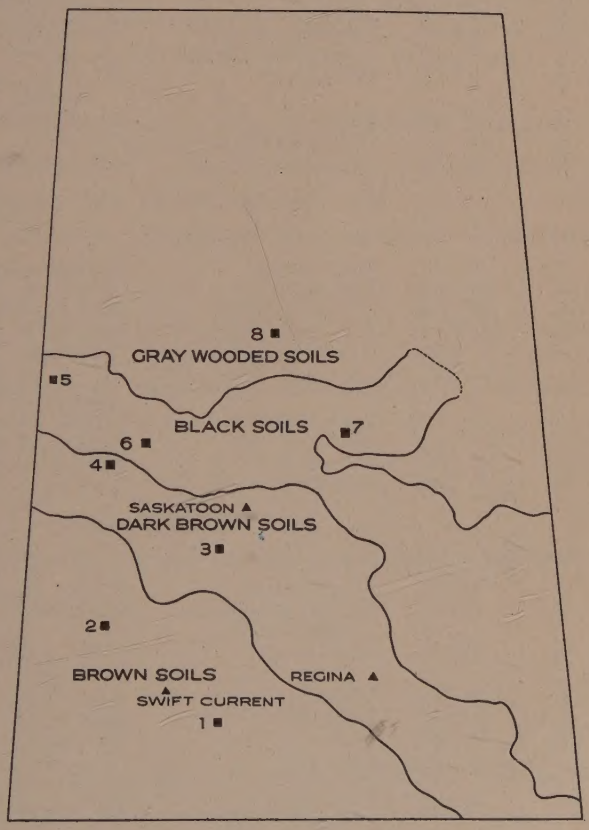

FIGURE 1. Showing main Soil Zones of Saskatchewan. The numbers refer to profile locations.

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correspond to the numbers used in designating the profiles throughout this paper.

DESCRIPTION OF PROFILES

The profiles as described below are placed in order of the main soil zones of the Province, beginning with the more arid brown soil zone of southwestern Saskatchewan and following in order to the dark brown and black soils of the central area and finally into the gray soil zone of the wooded area in the north and northeast part of the province.

Brown Soil Zone

*Profile No. 1. Brown loam on glacial till, Haverhill Series.**

Horizon	*Depth*	*Colour*	*Structure, etc.*
A_1	0″–3″	Gray-brown	Cloddy, faintly layered.
A_2	3″–7″	Brown	Top of long cloddy layer.
B_1	7″–11″	Brown	Long cloddy, somewhat compact.
B_2	11″–13″	Dark brown	Lower end of long cloddy.
B_3	13″–28″	Gray	Lime layer, some mottling with iron and lime splotches.

Profile No. 2. Brown loam on glacial till. Echo Series.

A_1	0″–3″	Dark brown	Thin platy, easily pulverized.
A_2	3″–7½″	Gray-brown	Cloddy; distinct platiness, easily pulverized.
A_3	7½″–9″	Light gray-brown (tends to ashy).	Thin platy (flakelike); easily pulverized.
B_1	9″–13″	Dark brown	Columnar, compact; breaks into hard angular fragments.
B_2	13″–18″	Brown	Like above but less compact.
B_3	18″–27″	Gray (brown)	Lime zone.
C	27″–42″	Gray	Calcareous parent till.

Dark Brown Soil Zone

Profile No. 3. Dark brown loam on glacial till. Weyburn Series.

A_1	0″–1″	Dark brown	Friable, soft granular, easily pulverized.
A_2	1″–4½″	Dark brown	Cloddy.
B_1	8½″–10″	Yellowish brown.	Same as above.
B_3	10″–13″	Pale grayish brown.	Lime layer.
C_1	2 ft.	Gray	Calcareous.

Profile No. 4. Dark brown loam on glacial till. Weyburn Series (Deeper phase).

A_1	0″–5″	Dark brown	Friable, granular, easily pulverized.
A_2	5″–11″	Brown	Long spike-like clods.
B_1	11″–17″	Dark brown.	Somewhat columnar and quite compact.
B_2	17″–24″	Gray-brown	Lime layer.

Black Soil Zone

Profile No. 5. Shallow black loam on glacial till. Oxbow Series.

A_1	0″–4″	Grayish black	Friable, granular.
A_2	4″–8″	Grayish black with brown tinge.	Granular to cloddy, friable.
B_1	8″–16″	Dark brown.	Long cloddy, slightly more compact than above.
B_2	16″–26″	Brown	Long cloddy.
B_3	26″–38″	Light yellowish gray	Lime layer.
C_1	38″–44″	Gray.	Calcareous till.

Profile No. 6. Black loam on lacustrine deposits. Blaine Lake Series.

A_1	0″–4½″	Gray black with brown tinge.	Platy, easily pulverized.
A_2	4½″–9″	Gray (ashy)	Platy (thick).
B_1	9″–18″	Dark coffee brown.	Columnar, breaking into hard angular fragments.
B_2	18″–24″	Gray.	Lime layer.

* Soil Series as named and described in Sask. Soil Survey Report No. 10 and former reports (15).

BLACK SOIL ZONE—*Concluded*

Profile No. 7. Deep black silt loam on lacustrine deposits. Melfort Series.

Horizon	*Depth*	*Colour*	*Structure, etc.*
A_1	0″–7″	Black to brown black	Soft granular, cloddy.
B_1	7″–18″	Dark gray brown.	Cloddy, friable.
B_2	18″–34″	Light gray brown.	Lime layer.
C_1	34″–42″	Gray, mottled.	Calcareous, structureless.
C_2	7 ft.	Gray	Calcareous lacustrine material.

FOREST GRAY SOIL ZONE

Profile No. 8. Gray loam on glacial till. Waitville Series.

A_0	½″	Organic debris	Structureless, easily pulverized.
A_1	½″–1½″	Dark fawn (slightly ashy).	Thinly plated, easily pulverized, gritty.
A_2	1½″–9½″	Ashy gray	Thinly plated, easily pulverized, gritty.
B_1	9½″–17″	Coffee brown	Compact, heavy in texture, breaks into angular fragments when dry.
B_2	17″–24″	Brown	Similar to above.
$B_3(C)$	24″–36″	Gray	Calcareous.

ANALYTICAL DATA[3]

Mineral constituents were determined from the Van Bemmelen-Hissink acid extraction method (17). Organic matter was determined by the Robinson McLean method (13). The hydrogen electrode was used to secure the pH values while carbon dioxide, sulphate, as well as other constituents were determined by standard analytical procedures. This data is included in Table 1.

TABLE 1.—ANALYTICAL DATA FOR PROFILES NO. 1 to NO. 8. RESULTS EXPRESSED ON OVEN DRY BASIS

Horizon	Depth	Insol. Res.	Base Sol. Silica	Al_2O_3	Fe_2O_3	CaO	MgO	CO_2	pH	N	OM
				BROWN SOIL ZONE							
Profile No. 1. Brown loam, Haverhill Series.											
A_1	0″–3″	77.9	8.49	2.74	2.36	0.52	0.58	0.13	6.22	0.34	3.10
A_2	3″–7″	75.0	11.00	3.90	2.94	0.45	0.76	0.07	5.94	0.18	1.58
B_1	7″–11″	77.7	9.30	3.05	2.78	0.54	1.05	0.25	7.52	0.11	1.19
B_2	11″–13″	75.6	9.65	3.61	2.71	0.94	0.93	0.44	8.34	0.11	—
B_3	13″–28″	57.3	8.92	3.23	2.91	9.59	2.84	9.55	8.64	0.09	—
Profile No. 2. Brown loam. Echo Series.											
A_1	0″–3″	66.3	14.30	3.79	2.51	0.35	0.57	0.11	6.17	0.24	5.75
A_2	3″–7½″	76.1	8.85	3.41	2.13	0.18	0.48	0.00	6.20	0.11	3.19
A_3	7½″–9″	80.9	8.05	2.97	2.10	0.19	0.50	0.00	7.07	0.10	2.19
B_1	9″–13″	63.6	15.6	6.44	4.21	0.29	1.34	0.11	8.51	0.09	—
B_2	13″–18″	64.5	14.00	5.37	3.40	1.28	1.71	1.26	7.76	0.06	—
B_3	18″–27″	53.8	14.00	5.57	3.52	6.41	2.25	4.22	8.10	0.06	—
C	27″–36″	54.0	15.30	5.96	3.73	4.45	2.13	2.61	7.95	0.05	—
	36″–42″	72.8	8.05	3.12	2.70	3.14	2.04	3.02	8.16	0.03	—
				DARK BROWN SOIL ZONE							
Profile No. 3. Dark brown loam. Weyburn Series.											
A_1	0″–1″	Not analyzed.									
A_2	1″–4½″	73.9	10.35	3.20	2.74	0.76	0.66	0.18	7.23	0.25	4.25
B_1	4½″–8½″	73.7	11.42	4.16	2.97	0.68	0.69	0.08	6.85	0.12	2.11
B_2	8½″–10″	75.4	10.63	4.40	2.78	0.74	0.81	0.00	7.67	0.12	1.67
B_3	10″–13″	59.3	9.16	3.60	2.62	9.11	2.53	8.40	8.40	0.10	1.42
C_1	2 ft.	59.7	18.25	4.34	3.02	4.06	4.10	4.25	8.56	0.03	—
Profile No. 4. Dark brown loam. Weyburn Series (deeper phase)											
A_1	0″–5″	74.4	9.76	3.32	2.44	0.63	0.66	0.00	7.20	0.27	5.81
A_2	5″–11″	73.9	10.73	5.07	3.39	0.56	1.00	0.00	7.07	0.19	3.29
B_1	11″–17″	70.5	12.16	4.70	3.64	0.75	1.21	0.20	8.15	0.10	1.13
B_2	17″–24″	65.0	11.78	4.91	3.39	4.47	2.05	3.57	8.50	0.03	—

[3] The analytical data reported in the following tables are mainly from analyses carried out in connection with the Soil Survey of Saskatchewan, a co-operative enterprise undertaken by the Soils Department, University of Saskatchewan, with assistance from the Dominion and Provincial Departments of Agriculture.

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TABLE 1.—ANALYTICAL DATA FOR PROFILES No. 1 to No. 8. RESULTS EXPRESSED ON OVEN DRY BASIS—*Concluded*

Horizon	Depth	Insol. Res.	Base Sol. Silica	Al_2O_3	Fe_2O_3	CaO	MgO	CO_2	pH	N	OM
				BLACK SOIL ZONE							
Profile No. 5.	*Shallow black loam.*		*Oxbow Series.*								
A_1	0″–4″	66.3	9.48	3.22	2.70	0.96	0.74	0.04	7.36	0.63	12.10
A_2	4″–8″	Not analyzed.									
B_1	8″–16″	73.1	8.90	3.91	3.16	0.62	0.80	0.00	6.43	0.29	5.26
B_2	16″–26″	78.0	9.15	3.86	3.14	0.35	0.99	0.00	7.31	0.10	3.17
B_3	26″–38″	64.5	8.92	3.75	2.91	6.44	1.79	4.20	8.27	0.06	0.92
C_1	38″–44″	67.2	9.80	3.95	3.15	4.72	1.90	3.57	8.49	0.04	—
Profile No. 6.	*Black loam.*		*Blaine Lake Series.*								
A_1	0″–4½″	68.9	9.47	3.81	2.73	0.76	1.48	0.00	—	0.50	9.95
A_2	4½″–9″	83.1	6.19	2.76	2.28	0.37	1.19	0.00	—	0.12	1.79
B_1	9″–18″	61.4	17.17	7.80	4.73	0.33	3.36	0.00	—	0.10	1.33
B_2	18″–24″	54.8	14.88	6.75	4.18	4.42	5.78	3.28	—	0.06	—
Profile No. 7.	*Deep black silt loam.*		*Melfort Series.*								
A_1	0″–7″	64.2	9.19	3.97	2.71	1.61	0.86	0.25	7.35	0.68	11.57
B	7″–18″	70.1	10.52	4.44	3.23	1.01	0.87	0.06	7.10	0.29	4.00
	18″–34″	66.3	7.95	3.07	2.36	7.68	1.86	6.48	8.55	0.06	0.88
C_1	34″–42″	53.6	13.57	6.85	3.13	7.23	1.68	5.40	8.60	0.06	—
	7 ft.	Not analyzed.									
				FOREST GRAY SOIL ZONE							
Profile No. 8.	*Gray loam.*		*Waitville Series.*								
				Total oxides							
A_0	0″–½″	Not analyzed.									
A_1	½″–1½″	91.1	2.65	2.82		0.28	0.37	0.00	6.90	0.08	—
B_1	9½″–17″	77.1	9.32	7.58		0.51	0.86	0.00	6.68	0.05	—
B_2	17″–24″	78.0	9.13	7.20		0.58	0.95	0.00	6.35	0.05	—
B_3	24″–36″	67.5	7.16	5.60		8.45	1.47	6.74	7.99	0.03	—
C	42″	62.1	10.3	7.26		6.42	3.22	6.05	8.24	0.03	—

Table 2 gives the exchangeable bases and the exchange capacity. Normal NH_4Ac (pH = 6.9) was used as the leaching solution for the removal of the exchangeable bases; for determination of total exchange capacity the soil was leached with neutral normal $Ca(Ac)_2$, with subsequent leaching of the Ca-soil with N/1 NH_4Ac to determine adsorbed Ca.

TABLE 2.—EXCHANGEABLE BASES. RESULTS EXPRESSED IN MILLIEQUIVALENTS PER 100 GRS. OF SOIL

Horizon	Depth	Ca	Mg	Na+K	Total	Total Exchange Capacity
			BROWN SOIL ZONE			
Profile No. 1.	*Brown loam.*	*Haverhill Series.*				
A_1	0″–3″	13.1	3.4	0.6	17.1	15.3
A_2	3″–7″	11.2	4.6	0.7	16.5	15.9
B_1	7″–11″	12.0	6.2	0.2	18.4	15.8
B_2	11″–13″	22.0	6.7	0.6	29.37	19.6
Profile No. 2.	*Brown loam.*	*Echo Series.*				
A_1	0″–3″	9.7	4.1	2.6	16.4	24.4
A_2	3″–7½″	4.2	2.8	2.5	9.6	14.0
A_3	7½″–9″	3.4	4.8	2.3	10.5	11.2
B_1	9″–13″	5.1	19.7	2.4	27.2	28.5

TABLE 2.—EXCHANGEABLE BASES. RESULTS EXPRESSED IN MILLIEQUIVALENTS PER 100 GRS. OF SOIL—*Concluded*

Horizon	Depth	Ca	Mg	Na+K	Total	Total Exchange Capacity
			DARK BROWN SOIL ZONE			
Profile No. 3.	*Dark Brown loam.*		*Weyburn Series.*			
A_1	0″–1″					
A_2	1″–4½″	18.8	1.5	2.2	22.5	19.5
B_1	4½″–8½″	16.2	2.4	2.9	21.5	18.2
B_2	8½″–10″	16.2	2.4	2.0	20.6	18.4
Profile No. 4.	*Dark brown loam.*		*Weyburn Series (Deeper phase)*			
A_1	0″–5″	14.6	5.1	1.5	21.2	20.2
A_2	5″–11″	11.1	7.6	0.5	19.2	19.8
B_1	11″–17″	10.8	13.6	1.5	25.9	23.8
			BLACK SOIL ZONE			
Profile No. 5.	*Shallow black loam.*		*Oxbow series.*			
A_1	0″–4″	25.9	8.8	2.9	37.6	35.2
A_2						
B_1	8″–16″	16.8	6.6	3.3	25.7	26.8
B_2	16″–28″	7.3	10.5	2.7	20.5	18.7
Profile No. 6.	*Black loam.*		*Blaine Lake Series.*			
A_1	0″–4½″	22.2	8.9	3.4	34.6	34.2
A_2	4½″–9″	7.8	5.4	1.5	14.8	13.2
B_1	9″–18″	5.2	23.4	1.8	30.6	29.4
Profile No. 7.	*Deep black silt loam.*		*Melfort Series.*			
A_1	0″–7″	49.5	9.8	–	59.3	59.9
B	7″–18″	27.3	6.9	–	34.2	33.6
			FOREST GRAY SOIL ZONE			
Profile No. 8.	*Gray loam.*		*Waitville Series.*			
A^2	1½″–9½″	11.0	4.0	–	15.0	13.4
B_1	9½″–17″	5.1	0.6	–	5.7	9.2
B_2	17″–24″	11.8	5.3	–	17.1	13.3

SOLUBLE CONSTITUENTS

Two profiles were examined for soluble salts and horizons having a considerable concentration were analyzed to provide information as to the nature of the soluble constituents. These results are given in Table. 3.

TABLE 3.—SOLUBLE CONSTITUENTS OF PROFILES 2 AND 5

Horizon	Depth	HCO_3	Cl	SO_4	Ca	Mg	Na (by diff.)	Total salts
Profile No. 2.	*Brown loam.*		*Echo Series*					
A_1	0″–3″							0.09
A_2	3″–7½″							
A_3	7½″–9″							0.15
B_1	9″–13″							
B_2	13″–18″							0.20
B_3	18″–27″	0.07	0.05	2.52	0.69	0.22	0.18	3.71
C	27″–36″	0.04	0.06	1.48	0.26	0.20	0.04	2.08
	36″–42″	0.03	0.02	0.42	0.05	0.06	0.02	0.59
Profile No. 5.	*Black loam.*		*Oxbow Series.*					
A_1	0″–4″							
A_2	4″–8″	Not analyzed.						
B_1	8″–16″							0.04
	16″–26″							0.11
B_2	26″–38″	0.04	Nil	1.03	0.23	0.10	0.10	1.54
C_1	38″–44″	0.04	Nil	0.63	0.11	0.09	0.07	0.96

DISCUSSION OF ANALYTICAL DATA

General

The effective moisture increases as one passes in a northerly or easterly direction from the southwest corner of the Province of Saskatchewan. In the northerly direction this condition is a result of lower average temperature, rather than from an increase in precipitation. In the easterly direction, however, an increase in precipitation does occur.

The geographical positions of the soil zones as indicated in Figure 1 reflect this climatic and resultant vegetational influence. The lime layer becomes progressively deeper on the average from the brown soils of the open plains to the gray wooded zone. Nitrogen and organic matter increase until the gray wooded soils are encountered. The relationship of climate and vegetation to the soil zone is more fully discussed in Soil Survey Report No. 10 (15).

Profile Development and Eluviation

An examination of the profile descriptions and of the analytical data given in Table 1 gives an indication of the degree of eluviation which has occurred. Profiles Nos. 2, 6, and 8 show distinct differences between the A and B horizons. The other profiles of the group are not notably differentiated. In the former group the development of eluvial and illuvial horizons has progressed to the point where these soils may be definitely described as leached soils. Removal of colloidal materials from the surface layers has occurred and possibly some destruction of the clay complex has been associated with such movement. A comparison of the iron and alumina oxide content of the more contrasting profiles is of interest in this connection. In Table 4 the comparative amount of these constituents in each horizon of Profiles Nos. 2, 3, 5, 6, and 8 is given. By taking the combined sesquioxides found in the B_1 horizon as 100, the comparative amount in each horizon is readily seen. The slight variation indicated for horizons of profiles No. 3 and 5 is in harmony with other analytical data to be found in Table 1 and also with the descriptions of horizons in these profiles. Profiles Nos. 2, 6 and 8, on the other hand, as indicated previously, show sharp contrasts between the A and B horizons, not only in the sesquioxides but in base soluble silica and also in the degree of removal of the bases, calcium and magnesium.

TABLE 4.—COMPARISONS OF PERCENTAGES OF SESQUIOXIDES IN VARIOUS SOIL HORIZONS OF PROFILES 2, 3, 5, 6, AND 8

Horizon	Profile 2	Profile 3	Profile 5	Profile 6	Profile 8
A_1	63		90	58	
A_2	53	85		41	50
A_3	49				
B_1	100	100	100	100	100
B_2	84	100	96.5	90	95
B_3	90	95	95.5		83
C	93	98	98		96

Exchangeable Bases

A study of the exchangeable bases and total exchange capacity of these profiles provides some further information of interest in relationship to the character of the soils. The results are given in Table 2. The

influence of the presence of increasing amounts of organic matter on base exchange capacity is indicated by the comparison between the total exchange capacities of Profiles Nos. 1, 3, and 5. The texture in each case is loam, but the organic matter content is respectively 3.10, 4.25 and 12.1% while the base exchange capacity is 15.3, 19.5, and 35.2 milliequivalents per 100 grams.

The dominant exchangeable ions are calcium and magnesium. In no case are there large proportions of the alkalies (Na and K) present, and they are more or less uniform in quantity throughout the profile. The presence of exchangeable hydrogen is indicated in the A horizons of Profile No. 2 and in the B horizon of Profile No. 8 by the fact that the total exchange capacity is in excess of the sum of exchangeable bases. The pH values of these soils as given in Table 1 indicate slight acidity only.

A study of the ratio of exchangeable Ca to Mg is of interest in relationship to the degree of eluviation in these profiles. In Table 5 the ratio of Ca/Mg is given for the various horizons of the soils.

TABLE 5. RATIO OF EXCHANGEABLE CA TO MG

Horizon	Profile numbers							
	1	2	3	4	5	6	7	8
A_1	3.8	2.35	12.0	2.86	2.92	2.5	5.05	2.75
A_2		2.5			2.54	1.45		
A_3		0.71						
B_1	2.6	0.26	6.75	1.45	0.70	0.22	4.0	8.5
B_2	1.9		6.75	0.795				2.2

The ratio of exchangeable Ca to Mg is from 2.5 to 12. in the surface horizons. This value is less in the lower horizons of all profiles except in No. 8. In profiles No. 2 and 6 this ratio reaches the low value of 0.26 and 0.22 in the B_1 horizons; and it is also to be noted that the ratios of 2.35 and 2.5 for the surface horizons of these soils were the lowest of any in the group. Soils No. 2 and 6, as has already been pointed out, are distinctly eluviated types and some further discussion is to be given in a later section regarding their chemical nature and possible genesis. Profiles Nos. 4 and 5 have slightly higher exchangeable Mg than Ca in their B horizons. They are not notably differentiated nor are profiles Nos. 1 and 7 which have higher exchangeable calcium throughout. Profile No. 8, described as a gray loam of the forest region, shows strong eluviation. Exchangeable Ca exceeds Mg throughout this profile. Some further discussion is to be given this and other chemical conditions of the profile.

Soluble Salts

Determination of the kind of soluble salts in many soils in the Province of Saskatchewan have lead the authors to conclude that sulphates of calcium, magnesium and sodium are the most common. Calcium and magnesium usually exceed sodium. The presence of chlorides in any amount beyond traces is not usual and the occurrence of sodium carbonate is relatively uncommon. The soils of this study were examined for the presence of concentrations of salts in the profile. The lower horizons of Profiles Nos. 2 and 5 showed considerable concentrations, and the constituent salts were determined in such horizons. The results are given

in Table 3. It may be noted that the concentrations occur in the lower B horizons and also that the salts are predominantly sulphates of Ca, Mg and Na, the latter being present in the smallest quantities.

Reaction

Extremely alkaline or extremely acid soils are uncommon in Saskatchewan. Out of many tests conducted on surface samples and on horizons of profiles few have been more acid than pH 6.0. On the other hand, while most samples show reactions on the alkaline side of neutrality, comparatively few are more alkaline than pH 8.5. The lime layer usually has a reaction of about this value.

The surface layers of Profiles No. 1 and 2 are slightly acid; the lower layers, however, are alkaline, as may be expected in the presence of free lime. Both profiles were obtained from the more arid Brown Soil Zone. Profile No. 8, although from the more moist wooded zone, does not indicate the degree of acidity commonly associated with such soils. Many samples of similar soils have been tested with similar results. The gray soils of the wooded area of this Province so far encountered are only slightly acid in reaction.

DISCUSSION OF CHEMICAL DATA IN RELATION TO MORPHOLOGY AND GENESIS

Several publications (7, 15) have dealt with the occurrence, morphological descriptions and possible genesis of the soils of Saskatchewan. The relationship of these soils to world groups has been suggested, although it was recognized that more chemical and other laboratory data were desirable before a complete parallel should be drawn between Saskatchewan soils and the "solonetz", chernozem" or "podsolic" soils originally described by European workers. It is possible that the use of this terminology is somewhat misleading, since some of the chemical features commonly ascribed to solonetzic and podsolic soils are absent in Saskatchewan soils of similar morphological character. Nevertheless, the conceptions of climatic relationships and morphological character in the classification of soils was of great value to the progress of soil surveys in this area as well as in other parts of the world.

Discrepancies between morphological descriptions and chemical data have been observed by many investigators, so that a new emphasis is likely to be placed on laboratory work in an attempt to interpret more completely field observations. The advantages which would result from the accumulation of definite quantitative criteria in relationship to soil character are many. Neutralization, to some extent at least, of personal error in recording profile descriptions, is one of them. It must be remarked, however, that field observation is of paramount importance, since the accuracy of laboratory results depends upon how well the samples obtained represent the various horizons of a given soil profile.

Solonetzic Types

Soils having the morphology of solonetz and solodized solonetz types are common in Saskatchewan. Attention has been drawn to solodized soils occurring in some areas as eroded complexes (7, 15) where the A horizons are more or less completely removed in irregular patches, leaving a shallow pit-like micro-relief. The latter have been locally termed

"burn-out" or "blow-out" soils in the provinces of Saskatchewan and Alberta. The topography of such areas is usually level to gently undulating.

Profiles Nos. 2 and 6 are typical both morphologically and chemically of leached solonetzic types found in Saskatchewan. However, the element sodium does not appear to have played an important role in their profile development. Calcium and magnesium are the dominant exchangeable ions, the latter being in excess of calcium in the B horizon. Kelley (8) has drawn attention to apparently similar conditions in solonetz-like soils of California. Ellis and Caldwell (4) have described such soils occurring in Manitoba, and have used the term, "magnesium solonetz", in describing them. Rost (14) also has reported on somewhat similar soils.

Kellogg (9) has recently reviewed the theory advanced by Gedroiz regarding the role of sodium in the genesis of solonetz soils. However, it appears that there are areas of soils on this continent as well as in Europe (5, 16) which, while appearing to be morphologically typical of the solonetz, have not the chemical character usually associated with these soils, at least in so far as the presence of excess exchangeable sodium in the profile is concerned.

The presence of considerable exchangeable magnesium might lead to the inference that the influence of magnesium is similar to that of sodium. However, there appears to be little evidence at the moment that the magnesium ion would act as a deflocculator of clay colloids. Sushko (15), while concluding that the degree of solodization is roughly comparative to the accumulation of exchangeable magnesium in the lower solum, does not associate the genesis of the profile with this condition. In Saskatchewan increasing ratios of magnesium to calcium in the B_1 horizon of solodized soils appear to be associated with a greater degree of downward movement of material in the profile. This is illustrated in Table 5 in the low calcium magnesium ratios of the strongly eluviated profiles Nos. 2 and 6, already discussed in a previous section.

The presence of soluble salts in the lower horizons is a fairly common feature in Saskatchewan soils, particularly in solonetzic types. The salts present in the leached profile No. 2, while higher in concentration, are similar in constitution to those found in profile No. 5. The relatively high percentage of calcium and magnesium minimizes the possibility that considerable sodium exchangeable may have existed in a solonchak stage. The analysies of soluble salts reported here are quite typical for soils of this Province. It would therefore be difficult to explain the leaching effects on the basis of the dispersive influence of sodium in earlier stages of profile development.

Norton (12) and Bray (1), in studying the Prairie soils of Illinois, consider that clay pan formation is largely due to the translocation of fine clay particles from eluvial to illuvial horizons. Bray further consideres the fine clay colloid (probably 0.1μ or less in particle size) may undergo movement when only slightly unsaturated. Jenny and Smith (6) consider the presence of electrolytes, carbonates and certain sols to be factors influencing the retention of such colloidal material in the B horizon. A prominent morphological feature in solidized soils in Saskatchewan is their compact, impervious, highly colloidal B horizon, which is underlain by a lime accumulation zone and a zone of soluble salts ($CaSO_4$, $MgSO_4$.

Na_2SO_4, etc. See Table 3). The A horizon is almost structureless, is quite friable and has suffered moderate leaching.

Slight unsaturation is common in the A horizon of solonetzic types in Saskatchewan, and the clay material, especially in the upper B horizon, appears to exist in a highly dispersed state. Flocculation is induced in the lower B horizon through the presence of calcium carbonate and various soluble salts. The ease of dispersion which appears to characterize the clay of these soils is possibly related to the type of parent material from which tney are derived. Edmunds (3) and Joel (7) have suggested that the occurrence of eroded solonetzic types of soil in Saskatchewan is correlated with the presence of non-calcareous shales which underlie the till at shallow depths in many such areas. It is possible that downward movement of finely divided and easily dispersed clay, such as might originate from these shales, accounts in part at least for the highly colloidal B layer of solonetzic types in Saskatchewan.

X-ray diffraction studies (2) further bear out the probability that the nature of the clay fraction of such soils is influenced by the mineralogical make-up of the clay fraction of the parent materials. The clay fraction of such soils requires further study before the pedogenic processes connected with their formation can be satisfactorily explained.

Podsolic Types

Profile No. 8 is typical for soils found over a large area of the wooded zone in northern Saskatchewan. The A and B horizons have the morphology generally described for soils of the podsol group. The chemical data given in Table 1 show that considerable weathering and movement of material has occurred in the profile. This is substantiated in the data giving exchangeable bases and exchange capacity (Table 2) and further illustrated by Table 4.

However, in contrast to the chemical nature usually ascribed to such soils, there is the presence of free lime at shallow depth, the slight acidity of the profile, and the fact that calcium remains the dominant exchangeable ion throughout the profile. The presence of lime in the subsoil does not preclude the possibility of the surface becoming highly leached, but dependent upon the type of natural vegetation would affect the degree to which such leaching might progress. The podsolic types in Saskatchewan commonly occur under a forest vegetation of deciduous trees, mainly poplar species. This type of vegetation would undoubtedly tend to return a greater amount of calcium and other bases to the surface in leaf fall than the conifers, and this may account for the fact that these soils are rarely markedly acid in reaction.

It is suggested by Leahey (10), in discussing the podsolic soils of Alberta, that conifers may have in the past been more prominent in the vegetation of such areas than is now the case. Moss (11), however, has pointed out that in Saskatchewan podsolic types occur both under pure deciduous as well as under mixed deciduous and evergreen stands.

Podsolic types in Saskatchewan occur on a variety of parent materials, including glacial lacustrine and sandy alluvial deposits. The lighter textured soils are, of course, most strongly leached, and also the most acid in reaction.

A forthcoming publication by Moss (11) will deal in greater detail with the morphology and chemical composition of podsolic types of Saskatchewan.

SUMMARY

Chemical data including exchangeable bases, and for certain profiles soluble salts, are given for profiles representative of the main soil groups in Saskatchewan.

Two types of leached profiles are represented. These are the leached soils of the grassland areas, which have the morphology of solonetzic soils, and the leached soils of the wooded areas, which are podsolic.

A relatively small proportion of exchangeable sodium is found in the solonetzic types. The presence of an excess of exchangeable magnesium over calcium in the B horizon appears to be typical of solonetzic soils in the area but this element is not considered to be solely responsible for the dispersion and subsequent movement of colloidal material within the profile. The nature of the clay minerals of the parent material is considered to be of importance in relationship to the formation of the compact, impervious, highly dispersed clay-pan-like B horizon of such soils.

Podsolic types are found under deciduous forest vegetation. Although they have been strongly leached, their present reaction is only slightly acidic, and calcium remains the dominant exchangeable ion throughout the profile.

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"ALKALI" SOILS IN SASKATCHEWAN[1]

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There is a large area of saline soils in the Province of Saskatchewan. The soluble salts present in such soils are variable both in kind and amount and also in their distribution throughout the soil profile. According to computations made by MacFarlane (1), 1391 square miles or roughly 900,000 acres, are shown on the soil survey map (4) as alkali soil areas. This does not include numerous small sloughs or flats which could not be indicated in the scale of mapping used in the survey, nor does it indicate the area affected within the boundaries of a soil series such as the Yorkton (4) with its associated localized saline areas.

The greater acreage of saline soils is to be found in the more arid brown and dark brown soil zones (4) of the southwestern part of the Province. Snow white crusts of salts at the margin of lakes or on dry lake beds and alluvial flats are a common sight in the southwest. In general this type of land is of low value. Where the salinity is not too high, fair native grass is to be found and such land is useful for pasture. However, both the quantity and the quality of the feed grown on such areas is poor, as a rule. It may be remarked that certain saline lakes of this area have proven valuable as sources of sodium sulphate.

In the eastern part of the province there is also a considerable acreage of saline soils. This area in the main lies within the more moist black soil zone (4) and is more or less coincident with the soils of the Yorkton series. The presence of soluble salts is not so readily recognized here since climatic conditions promote their distribution in the soil profile, and surface crusting is somewhat less common. On reference to the soil map (4) it is noted that the largest continuous area of saline soil in the province is in this eastern part, namely, in the ancient lake-bed and drainage channels of the Quill Lakes. Saline soils are less common in the northern areas, but are occasionally encountered even in the gray soil zone of the northern forest region. Saline peats have been found as far north as the National Park north of the city of Prince Albert and in other localities within this zone.

In addition to the soils which have soluble salts in concentration at the surface, there are the types which have horizons of salt accumulation in the subsoil. This condition is not readily perceivable and the large amounts of soluble salts present at comparatively shallow depths are often only revealed by chemical analysis. Salinized horizons of the subsoil are characteristic of such soil series as the Echo and Elstow (4) but are also present in certain phases of other series.

It appears unlikely that any but a small proportion of the soluble salts found in Saskatchewan soils originate through weathering which has occurred since glaciation.

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[1] Read before a meeting of the Soils Group of the C.S.T.A. at the University of Saskatchewan, Saskatoon, Canada, June 28 to 30, 1937.

[2] Professor of Soils, University of Saskatchewan.

COMPOSITION OF SALTS FOUND IN SASKATCHEWAN SOILS

The sulphates of calcium, magnesium and sodium are the predominant salts present in saline soils of this province. Chlorides are present in some samples, but it is common to find only traces of the chloride ion present in making an analysis. In many cases calcium sulphate is present in the greatest amounts and sodium sulphate the least. Observations indicate that the toxicity of the salts increases with increasing percentages of sodium, and especially so with sodium chloride. Analyses reported by Shutt and Smith (3) on samples obtained from near Maple Creek, Sask., indicate sulphates of calcium, magnesium and sodium as the compounds present. Sodium sulphate was the chief component present in two sets of samples obtained from land which had been under irrigation some years.

Sodium carbonate (black alkali) soils are of infrequent occurrence in Saskatchewan. A few patches occur near the town of Wilkie and a profile analysis from one of these will be presented later in this paper.

The following description and analysis is of samples obtained near Langenburg in eastern Saskatchewan. This soil may be considered as a salinized phase of the Yorkton series.

A description of the three horizons of the profile analyzed is as follows:

0 – 8″ Very dark gray, soft cloddy friable loam, specks of lime or salts. Moderate effervescence.

8 – 13″ Similar to above, slightly more compact, and with less organic matter.

13 – 22″ Compact yellowish clay loam, mottled and becoming bluish gray at lower depths.

Impeded drainage is evident in this profile. The topography was flat and surface drainage rather poor at the point where the sample was obtained. There was a good cover of grass and shrubs, and a few yards away the land was under cultivation. According to the farmer who was cultivating the nearby field, the grain crops did not suffer except in drier seasons.

TABLE 1.—SOLUBLE CONSTITUENTS OF LANGENBURG PROFILE*

Depths	0 – 8″	8 – 13″	13 – 22″
pH	8.5	8.2	8.8
Ca	0.304	Not determined	0.602
Mg	0.266	Not determined	0.158
Na (by diff.)	0.190	Not determined	0.142
SO_4	1.818	Not determined	2.138
Cl	0.014	Not determined	0.007
CO_3	Nil	Not determined	Nil
HCO_3	0.055	Not determined	0.024
Total salts	2.643	2.058 (by ign. of residue)	3.071

* Analyses reported in this paper are by the conventional 1 : 5 dilution with shaking for one-half hour.

The predominance of calcium sulphate in the above analysis may be noted. This salt increases with depth, while magnesium and sodium tend to decrease. This condition, however, would be subject to variation with

fluctuations in moisture. The amount of chloride ion present is quite small and there was no carbonate ion indicated.

A surface sample from a small local area on the University farm at Saskatoon gave the following results on analysis:

Depth	0 – 6″
pH	6.7
Ca	0.123
Mg	0.186
Na (by diff.)	0.248
SO_4	1.236
Cl	0.103
CO_3	Nil
HCO_3	0.017
Total salts	1.913

This sample was obtained from the edge of a patch at a point in rows of barley judged to be the limit of tolerance for that crop. Nearby rows of wheat and alfalfa indicated a limit of tolerance of 1.023 and 1.167% total salts. The texture of this soil was clay loam.

Sulphates are predominant in this analysis as in the Langenburg profile, but sodium sulphate is present in larger quantities than either calcium or magnesium sulphate in this case. There is also somewhat more chloride ion than was found in the Langenburg soil. Chlorides do not usually make up a large proportion of the soluble salts present in soils of this province; in fact, as stated above, the chloride ion is generally present only in traces. However, a few samples have been found in which the salts present were mostly chlorides.

Sodium Carbonate Soils

A sample of soil containing sodium carbonate was brought to this department by a farm owner who had noted several small patches of barren soil with a surface of unusually dark-coloured, oily appearance. The patches were being cultivated and sown along with the remainder of the field and according to the owner had never produced any vegetation whatsoever. A patch examined by the writer was found to be within an area of undulating glacial loam (Weyburn series) and was about 40 feet in diameter. The topography was flat but not depressional. The edge of the patch was very sharply defined, the crop of oats being normal in appearance within one foot of the barren area. The surface was dark brown to black in colour and of a rather greasy appearance.

The soil profile was examined within the barren patch and the profile description is as follows:

0 – 4″ Dark coloured surface soil cultivated. A very thin surface crust was in evidence. Moderate effervescence.

4 – 8″ Reddish brown, slight platiness, rather compact, slight effervescence.

8 – 16″ Brown, small cloddy with faint platiness, moderate effervescence.

16 – 24″ Gray brown, mottled, strong effervescence. The parent material appeared to be till of medium texture.

Samples were obtained from this profile and also a sample of surface soil at a distance of 10 feet from the edge of the patch where crop growth appeared quite normal.

The analytical results on the above samples are given in Table 2.

TABLE 2.—SOLUBLE CONSTITUENTS OF SODIUM CARBONATE SOIL

Depth	0 – 4″	4 – 8″	8 – 16″	16 – 24″	Sample taken outside barren area 0 – 6″
pH	10.06	9.90	8.76	8.46	8.42
Ca	0.016	0.009	0.013	0.280	—
Mg	0.006	0.003	0.013	0.052	—
Na (by diff.)	0.220	0.111	0.077	0.044	—
SO_4	0.058	0.040	0.115	0.872	Trace
Cl	0.068	0.017	0.031	0.024	Trace
CO_3	0.181	0.100	0.002	0.000	—
HCO_3	0.023	0.000	0.055	0.027	0.04
Total salts	0.572	0.280	0.306	1.299	0.07

From the above analysis it may be observed that sodium carbonate is present in considerable quantities in the first and second horizons. In the 8–16″ depth, the carbonate radical is present in traces only and is entirely absent in the lower depth. The pH of the profile horizons substantiates the analysis, inasmuch as the results show a decline from the surface horizon of 10.06 to pH 8.46 in the lower horizon. It is obvious that there is excess calcium sulphate in the lower horizon which would prevent the formation of soluble carbonates. The pH of 8.46, while fairly alkaline, is not beyond the alkalinity which may be due to calcium carbonate (5). The surface 8″ of this profile is apparently a typical "black alkali" soil, but the subsoil is of the "white alkali" kind. Sodium chloride and sodium carbonate decrease with depth, while calcium and magnesium sulphates increase.

There is probably very little movement of soluble constituents within this profile due to the rather impermeable nature of the 4–8″ horizon. However, if the excess salts were to leach to the lower horizons, dispersion and downward movement of clay constituents would no doubt be intensified. It may be noted that the sodium carbonate on reaching the subsoil horizons would be converted into sodium sulphate and therefore a marked reduction in the alkalinity of the profile in terms of pH would follow. Solonetzic soils are common in Saskatchewan and it is possible that the commonly described process of formation has been effective in their development. On the other hand, sodium carbonate soils are rarely found in this province, exchangeable sodium is present in only small amounts in soils of solonetzic morphology (2), and sodium salts are generally present in smaller proportion in saline soils than either calcium or magnesium. The latter facts would indicate the possibility that other theories than the sodium theory may be necessary to explain the formation of soils of solonetzic morphology in this region.

Salinized Subsoil Horizons

Salinized horizons of the subsoil are frequently encountered in the soils of Saskatchewan, especially in those of a solonetzic type of morphology. Normal profiles of such soils as those of the Melfort, Regina and Waitville series (4) are free of such layers but they are occasionally present in the Haverhill, Weyburn and Oxbow (4).

The following profile description is that of an Echo type (4), a soil of solonetz-like morphology. A patchy erosion of the A horizon of this soil results in the shallow pit-like micro-relief locally termed "burn-out" land.

Depth	*pH*	*Description of horizons*
0 – 3″	6.17	Dark brown, thin, platy, easily pulverized loam.
3 – 7½″	6.20	Gray brown, cloddy, distinctly platy, easily pulverized.
7½ – 9″	7.07	Light gray, flake-like, easily pulverized.
9 – 13″	8.51	Dark brown, columnar, hard and compact, heavy.
13 – 16″	7.76	Brown, similar to above but less compact.
18 – 27″	8.10	Grayish brown, lime zone.
27 – 36″	7.95	Gray calcareous till, gypsum and other salts.
36″+	8.16	Gray calcareous till; parent material.

The horizons above 18″ contained less than 0.2% total soluble salts, so the constituent ions were not determined. The results of determinations on the remaining horizons are given in Table 3.

TABLE 3.—SOLUBLE CONSTITUENTS IN LOWER HORIZONS OF A SOLONETZIC TYPE

Depth	18 – 27″	27 – 36″	36″+
pH	8.10	7.95	8.16
Ca	0.668	0.260	0.054
Mg	0.216	0.196	0.059
Na (by diff.)	0.180	0.040	0.020
SO_4	2.520	1.480	0.417
Cl	0.053	0.064	0.017
CO_3	Nil	Trace	Trace
HCO_3	0.071	0.045	0.027
Total salts	3.708	2.075	0.594

The percentage of soluble salts increased sharply from 0.20% in the 13″ to 18″ horizon to 3.708% in the 18″ to 27″. Below 36″ there was a drop to 0.59%. Calcium is in excess throughout the salinized layers and the salts are again predominantly sulphates. There is no indication of sodium carbonate in any horizon of the profile.

Whether or not such shallow salinized layers affect plant growth is not certain. The plant roots would no doubt penetrate to greater depths, but it is unlikely that available moisture would exist beyond the depths where salt accumulation is encountered. The compact, impermeable nature of the upper B horizons of such soils is probably more detrimental to the growth of plants than is the salinity of the lower layers.

A more detailed and intensive investigation of saline soils is at present under way[3]. It is hoped that from the results of such investigations more definite information on the limit of tolerance of different crops for the various types of salts encountered may be obtained. It is significant of the importance of this problem that more samples are submitted to this Department for examination because of "alkali" than for any other condition. In a large percentage of cases the cause of unsatisfactory production is not suspected by the farmers or others submitting such samples. The recent progress in the development of irrigation projects in this Province makes the study of saline soils and related problems of additional importance.

[3] With financial assistance for Soil Research under the Prairie Farm Rehabilitation Act.

SUMMARY

Saline soils are of widespread occurrence in the Province of Saskatchewan. The soluble salts present are commonly sulphates of calcium, magnesium and sodium, the chlorides being relatively uncommon. Sodium carbonate is of infrequent occurrence in the soils of the area.

The analyses indicate that calcium and magnesium predominate over sodium in the saline soils examined. The analysis of the sodium carbonate soil indicates that sodium carbonate may in some cases be confined to surface layers. In this profile only the upper eight inches contained this salt. Salinized subsoil layers are of frequent occurrence in the Province of Saskatchewan.

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SOME OBSERVATIONS ON SOIL SURVEY WORK IN SASKATCHEWAN[1]

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INTRODUCTION

This paper constitutes a brief review of soil survey work in Saskatchewan together with a discussion of some of the problems involved and suggestions regarding future activities. In order to appraise the work accomplished to date, it is advisable to outline the origin of the survey. In 1920 the provincial government, at the request of numerous residents of southwestern Saskatchewan, held a Better Farming Conference at Swift Current. This conference was attended by technical agriculturists and practical farmers, who met to discuss the problems arising from several years of drought and soil drifting. As recommended by the Conference, a Royal Commission was appointed to investigate the condition of agriculture in the area, and from a recommendation of the latter body the Saskatchewan Soil Survey was created.

In view of the present activities in soil survey and land utilization work, it is worthwhile noting some of the specific recommendations of the Commission as quoted from the report (2).

"1. That a reconnaissance soil survey of Saskatchewan be undertaken to outline the various soil areas and classify them as to their suitability for grain growing and stock raising; and that the reconnaissance survey be followed by a more complete agricultural survey in order to render the investigational work of the Agricultural College and Experimental Farms more effective.

"2. That areas unsuitable for grain growing be converted into community pastures.

"3. That rural municipalities be given power to prevent the cultivation of sandy lands which blow to such an extent as to be detrimental to adjoining farm lands.

"4. That experiments be undertaken with a view to determining the varieties of grasses and the methods most suitable for rendering such areas fit for grazing purposes."

The Commissioners also discussed the scope of the proposed survey, and their conclusions were as follows: "The soil survey is not to be regarded as a relief measure from which immediate results will accrue. It is not a cure-all of difficulties, and in itself is not an end but rather a means to an end. But it *will* assist in anticipating future difficulties, in putting agriculture on a permanent basis and in guiding investigational work."

"The type of survey deemed suitable to Saskatchewan conditions is one intermediate in scale between a reconnaissance and a detailed survey." It was pointed out that a detailed survey is adapted to regions of intensive agriculture where the high cost per acre is justified, and to less fertile but

[1] Read before a meeting of the Soils Group of the C.S.T.A. at the University of Saskatchewan, Saskatoon, Canada, June 28 to 30, 1937.

[2] Soil Specialist under the Prairie Farm Rehabilitation Act (P.F.R.A.).

more humid regions where the use of soil amendments is profitable. On the other hand, a superficial reconnaissance survey does not provide sufficient detail to be of full benefit to the farmer and investigator.

"The soil survey should be conducted with the University as the central point of activity and the work should begin in the southwest and be extended throughout the province."

The Commission also stressed the necessity of controlling soil drifting. Reference to the need for reclaiming badly drifted soils is also given in the first soil survey report (3) which covered part of the sandy area extending from Caron to Mortlach, a district which is at the present time one of the serious problem areas of the Province.

SOIL SURVEY WORK PRIOR TO 1936

The Saskatchewan soil survey was directed at first by Prof. Roy Hansen, later by Prof. A. H. Joel, and at the present time by Dr. J. Mitchell. The survey progressed slowly but steadily until 1929, when the Central Experimental Farm co-operated in the work, almost perished in 1932, due to lack of nourishment, and in 1936 grew again in size and vigor through the assistance of the P.F.R.A. The latter project, like the soil survey, came into existence as a result of drought, soil drifting and agricultural depression.

The first seven survey reports (3) cover relatively small areas mapped approximately to a detailed reconnaissance scale. Reports Nos. 8 and 9, covering portions of southwestern Saskatchewan, were mapped on a broader scale. All areas covered in the first nine reports are included in Report No. 10, published in 1936 as the *Reconnaissance Soil Survey of Saskatchewan* (3). The development of soil science since the beginning of the survey is reflected in the later reports by the prominence given to genetic factors of soil formation and the use of the soil profile as the basis for soil classification. The broader scale of mapping was adopted in order to speed up the work. This was made necessary by the large area to be covered, the demand for soil information, and the fact that only one or two field parties were available.

The publication of the reconnaissance map and report marks the virtual completion of the first stage of soil investigations in Saskatchewan. It is true that the report does not cover the whole of the settled area of the province, and that the detail is not sufficient to classify individual farms. Nevertheless, the report deals with all the extensive agricultural soils in use at the present time and provides an excellent basis for future agricultural policies and investigations. The combined information supplied by the map and report may be said to summarize our present knowledge of Saskatchewan soils.

PRESENT PROBLEMS OF THE SOIL SURVEY

In 1936 the Saskatchewan Soil Survey carried out three distinct types of survey work. These were: detailed reconnaissance surveys of wind eroded soils at Mortlach, Cadillac and Hodgville; a more detailed survey of the Eastend, Val Marie and Teo Lake irrigation projects; and reconnaissance mapping in the unsurveyed areas of northern Saskatchewan.

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At the present time the first mentioned type of survey is receiving most attention and the work has been broadened to include the mapping of other "problem" soils. These include all types of light textured soils, all severely drifting types, poorly drained soils, soils associated with rough topography and excessive stoniness, and those having inherent undesirable characteristics, such as the extreme solonetz or "blow-out" types. The work has been arranged to cover certain rural municipalities and in this way the survey data will be of greater value to governmental departments which are accustomed to dealing with individual municipalities. The present survey is also designed to fit in with the land utilization studies conducted by the Department of Farm Management.

It will be evident that most of the surveys now in progress are being conducted in areas already covered by the reconnaissance survey. An important problem therefore is that of selecting a suitable scale of mapping, which on the one hand will justify a re-survey of certain areas, and on the other, will not be too slow and costly. In the case of the surveys of selected municipalities, the object is to obtain information sufficient to arrive at the potential agricultural value of each quarter section. In particular the aim is to map closely the boundaries between arable and non-arable soils. The land is being covered by a combination of foot and car traverses, the better types of soil being covered more quickly as they do not constitute a serious problem as do the poorer soils. The field data is placed on township sheets on a scale of 2 inches = 1 mile. The completed work will probably be shown on municipal maps on a scale of 1 inch = 1 mile.

A number of other problems have to be settled during the course of the field work. It is obvious that in the reconnaissance survey many features could not be shown on the map, and a number of different though related factors had to be grouped together. In the more detailed surveys now in progress it becomes necessary to decide how far it is advisable to differentiate minor soil and topographic features. The mapping of topography is a case in point. With the exception of soil texture no single factor is more important than that of topography. Relatively slight changes in slope profoundly influence profile characters, moisture efficiency and the amount of land which may be cultivated. Nevertheless it is not feasible to separate every variation in topography, since it is often difficult to decide where the boundary lines should be placed. The problem is complicated by the fact that in a glaciated region such as Saskatchewan a great deal of the surface is characterized by various phases of rolling topography. For example, a smooth 4% slope extending over a whole quarter section represents very different conditions of soil and agricultural use from the same slope occurring as a series of ridges and depressions. In the former case the topography can be mapped by simply measuring the slope, while in the latter the frequency or number of "rolls" per half mile must also be taken into consideration. It is expected that the various topographic phases now being mapped may eventually be grouped according to percentage slope and frequency, so that such a term as "gently rolling" may be designated by measurable units.

Much of the present survey work is carried on in areas affected by wind erosion, where the original soil profiles have been altered by soil drifting. In some cases the soils are buried under drifted material, while

in others all or part of the profile has been removed. Frequently both conditions occur in close proximity and the area has to be designated as one in which both accumulation and removal have taken place. Variations in the degree of accumulation or removal also occur and it is frequently impossible to map all the phases of soil drifting which may be found on a single quarter section.

The degree of wind erosion is shown in the map by the use of symbols which indicate the amount of damage suffered by the soil, and, in some measure, the loss of fertility. The latter factor is difficult to estimate, since it depends both upon the severity of erosion and the type of parent material. Wind erosion on Regina heavy clay, while it represents a serious loss of potential fertility, may still leave the soil reasonably productive. A similar degree of erosion on Hatton fine sandy loam may destroy the present fertility of the soil. In mapping wind eroded soils consideration must also be given to the composition of the drifted material, particularly where it forms the present surface of cultivated lands. Previous studies (1) have shown that the drift from sandy soils and from glacial loams and clay loams is lighter in texture and lower in potential fertility than the original soil. In the case of the heavy lacustrine types the soil and drifted material are practically identical. It will be seen that wind erosion is far more destructive on the first mentioned soil types, and that the loss of fertility is correspondingly greater.

Another problem of the present surveys is concerned with the mapping of soil complexes. In certain areas frequent variations in parent materials, local climatic factors, topography and drainage result in the occurrence of intricate mixtures of soil series and types. These mixed soils occur so frequently and over such small areas that they cannot be shown separately on the map. It is therefore necessary to group several series or types together and in such cases each soil boundary is an arbitrary line and the final designation of the soils within the boundaries is a compromise.

In discussing the survey work now in progress it should be mentioned that the surveys of irrigation projects are being continued this year. These surveys are being made at the request of the Water Development Committee, P.F.R.A. They are designed, in conjunction with topographic data supplied by the engineers, to provide a classification of each parcel of land according to its potential value for irrigation. In addition to the ordinary field work, numerous soil samples are taken, in order to secure data on the soluble salt content, permeability, texture, structure and other soil features. The location of the samples and of important physical features is obtained by pacing and compass bearings. The Brunton compass is used for this purpose and also to measure slopes in the other surveys. This instrument has proved very useful as it combines reasonable accuracy with ease and speed of operation. The field work is performed by foot traverses and the mapping is done on a scale of 4 or 5 inches = 1 mile. The greater detail used in this type of survey is justified by the high cost of irrigation projects.

Further activity in the survey of northern Saskatchewan has been temporarily postponed owing to pressure of work from the other survey projects. The amount of unsurveyed agricultural land and the areas covered to date are listed in Table I.

TABLE 1.—THE RELATION OF SOIL SURVEYS TO LAND AREAS IN SASKATCHEWAN

Total area of Saskatchewan	155,764,480 acres
Area covered by reconnaissance soil survey	60,181,600 "
Area of settled land not covered by soil surveys	8,640,000 "
Area covered by detailed reconnaissance surveys	276,360 "
Area covered by irrigation surveys	10,000 "
Area under cultivation, 1936	29,871,550 "

CONCLUSIONS

A review of the present activities in soil survey, land classification and reclamation work in southwestern Saskatchewan suggests that some of the recommendations of the Better Farming Commission of 1920 are now being put into practice. It therefore seems logical at this point to consider the next stage of soil investigations in this province.

It is important that the reconnaissance survey of the northern areas be continued, in order to complete the inventory of the soils of Saskatchewan. Furthermore, the gray soil (podzol) region is associated with a number of important soil problems, and it is desirable that these be investigated in order to assist in the improvement of agricultural conditions in the newer settlements.

It will ultimately be necessary to decide how much of the province is to be re-surveyed in conjunction with land utilization studies. In this connection it may be pointed out that problems of soil management and land use are not confined to the present drought area. Wind erosion, for example, is becoming a serious problem on many of the lighter soils of the dark brown and black soil zones.

Regardless of the type of survey adopted or the purpose for which it is undertaken, one of the objectives of future projects should be the securing of additional fundamental knowledge of representative soil types. This involves considerable laboratory work in addition to the field studies. The use of laboratory data to support field observations becomes increasingly important as greater detail of mapping is required, and this is particularly true in the surveys of irrigation projects.

If the soil survey may be regarded as the basis for future agricultural policies and research, it may be said that the surveys already completed and those now in progress open the way to many lines of investigation. The soil survey, in addition to supplying soil and land utilization data, may be expected to assist in the solution of problems in agronomy, plant pathology, entomology, and other agricultural sciences.

The foregoing statement suggests the desirability of using the soil survey data to anticipate future problems, in so far as that is possible. It may be hoped that survey activities will not be confined to the poorest soils. The survey of these soils is made necessary by the present condition of agriculture, but ultimately it is more important to study the better soils and to assist in keeping them fertile and productive, since they are far more valuable than the poorer types. In fact it may be questioned whether the very poor soils warrant the time and cost required to make a fairly detailed survey, outside of the value of separating these soils from the better types. Such a survey can only be justified if it results in the adoption of a proper land use programme. In the long run soil conservation will pay better dividends than soil reclamation.

Finally, the future progress of soil science in this province requires that the work be established on a more permanent basis than has prevailed up to the present. The value of soil surveys and related investigations has been amply demonstrated in this and other provinces. The general recognition now accorded this fact would seem to warrant soil science being placed upon an equal footing with the other sciences which have become so vital a part of Canadian agriculture.

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KIND, POSITION, AND TOXICITY OF ALKALI SALTS IN CERTAIN ALBERTA IRRIGATED SOILS, AND TOLERANCE OF CROPS FOR THESE SALTS[1]

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INTRODUCTION

The introduction of irrigation in many additional localities by the water development activities of the Prairie Farms Rehabilitation Act has caused an increased interest in soil alkali, as accumulations of alkali salts often take place where moisture conditions of the soil are changed by the artificial application of water. For this reason any studies of aklali soils that have been made in western Canada may be useful to those who may meet this problem as irrigation is extended. Realizing this, it was thought advisable to present some alkali experiments conducted by the Canadian Pacific Railway some years ago.

The investigations reported here were inaugurated by the late Don. H. Bark, then Chief of the Irrigation Investigation Division, Agricultural Industry Branch, Department of Natural Resources, Canadian Pacific Railway, in connection with the Company's development of the Eastern Irrigation District in the vicinity of Brooks, Alberta. The work was conducted by the author under Mr. Bark's direction during the years 1917, 1918 and 1919. The data accumulated were reported to the Railway Company in three annual reports that have not been published. Recently the farmers of the Eastern Irrigation District organized themselves under the Irrigation Districts Act of Alberta, and the interests of the Canadian Pacific Railway in the land and water project were transferred to the district. Since this transfer, the Manager of the C.P.R. Department of Natural Resources has authorized the author to publish or otherwise use the data.

While these investigations were concluded 18 years ago, the data secured still may have application to our present day problems. It is not the purpose of this paper to present all of the data at this time but to make a comparatively brief report of those parts that seem to be of principal value. If it is deemed advisable later a more detailed analysis may be made.

MATERIAL AND METHODS

It is the purpose here to report:

1. The kind and amount of water soluble salts found at various soil depths and the change in position of the salts with irrigation.
2. The tolerance of crops for salts in the soils studied.
3. The ameliorating action of gypsum on other sulphates.

Soil samples were secured for analysis in several localities chiefly in the Tilley District, and it is the Tilley soils that are reported here as more detailed work was done with these soils than with any on the project. The soils in this district are mostly blow-out soils typical of the Tilley East

[1] Read before a meeting of the Soils Group of the C.S.T.A. at the University of Saskatchewan, Saskatoon, June 28–30, 1937.

[2] Assistant Superintendent.

PLATE I.—Wheat and barley grown on clay loam with different amounts of salts added to the soil. Reading from left to right the percentages of salts in the soil contained in the pots were: FIGURE 1.—Na_2SO_4—Nil, 0.25, 0.50, 0.75, 1.00, 1.25, 1.50; FIGURE 2.—$MgSO_4$—Nil, 0.30, 0.60, 0.90, 1.20, 1.50, 1.80; FIGURE 3.—Na_2CO_3—Nil, 0.025, 0.10, 0.20, 0.40, 0.60, 0.80, 1.00; FIGURE 4.—NaCl—Nil, 0.025, 0.10, 0.20, 0.40, 0.60, 0.80, 1.00; Wheat on the left half and barley on the right half of each pot.

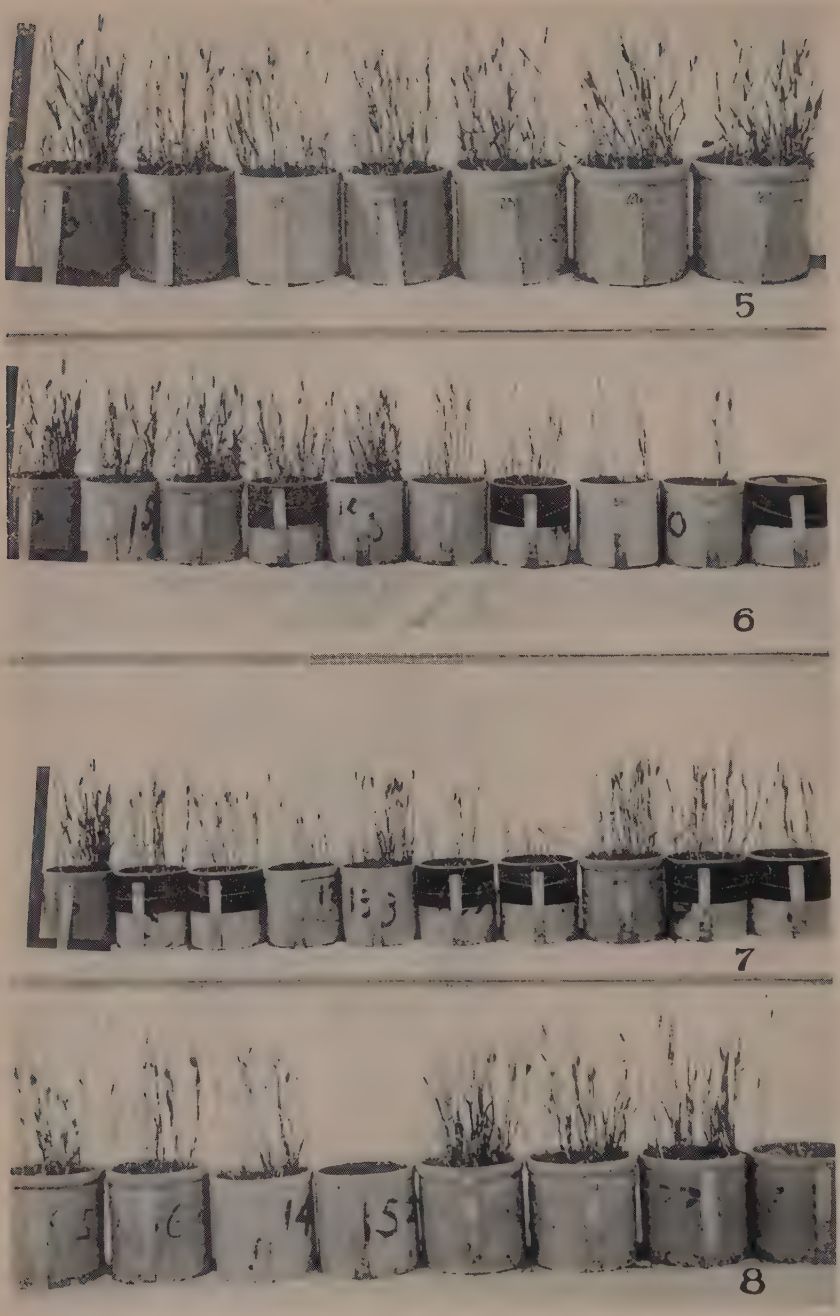


PLATE II.—Wheat and barley grown on clay loam with different amounts of salts added to the soil. Reading from left to right the percentages of salts in the soil contained in the pots were: FIGURE 5.—$CaSO_4$—(Nil) (5.0) (15.0) (5.0) (15.0) (5.0) (15.0). FIGURE 6.—Mixture of Na_2SO_4 and $MgSO_4$. The first amounts are Na_2SO_4: (Nil) (0.25–0.25) (0.25–0.75) (0.25–1.25) (0.75–0.25) (0.75–0.75) (0.75–1.25) (1.25–0.25) (1.25–0.75) (1.25–1.25). FIGURE 7.—Mixtures of Na_2SO_4 and NaCl. First amounts are Na_2SO_4: (Nil) 0.25–0.025) (0.25–0.20) (0.25–0.50) (0.75–0.025) (0.75–0.20) (0.75–0.50) (1.25–0.025) (1.25–0.20) (1.25–0 50). FIGURE 8.—Ameliorating action of $CaSO_4$: ($MgSO_4$–0.90) ($MgSO_4$–1.20) (Na_2SO_4–0.75, $MgSO_4$–0.75) (Na_2SO_4–1.25, $MgSO_4$–1.25) (Na_2SO_4–0.75, $MgSO_4$–0.75, $CaSO_4$–2.0) (Na_2CO_4–1.25, $MgSO_4$–1.25, $CaSO_4$–2.0) (Na_2SO_4–0.75) (Na_2SO_4–1.25).

area and some are relatively impervious to water. In determining the kind and position of salts the soil samples were secured in foot sections to a depth of six feet and determinations were made of the individual ions of the salts found in the water extraction except that no separation was made of the sodium and potassium.

The investigations regarding the tolerance of crops for salts were conducted either by placing soils of known salts content into three-gallon pots and growing crops on these soils, or by mixing salts with soils of low salts content and growing the crops on these soils in pots. Determinations were made also of the salts in field soils where alkali accumulations had occurred. In these field investigations, borings were made in the crop where no alkali injury was apparent, at the edge of the alkali spots where crops showed decided injury, and just at the edge of the areas where growth was entirely inhibited.

RESULTS

Kinds of Salts

The principal water-soluble salts found in all of the silt and clay soils and a few of the sandy soils were Na_2SO_4 and $MgSO_4$, with considerable quantities of $CaSO_4$. A few sandy soils contained appreciable amounts of Na_2CO_3 or $NaHCO_3$, but there was very little chloride in any of the soil investigated. As much as 1% of the Na_2SO_4 or $MgSO_4$ was found in some layers of the virgin soils, and in some instances the combined amount of these salts was almost 2%. In some of the soils there was about an equal amount of sodium and magnesium sulphate, while in some, magnesium sulphate predominated and in others there was more sodium than magnesium.

In determining the total soluble salts by evaporation of the water extraction, 4% of total water-soluble salts were found in a number of samples. Usually, however, where these high concentrations were present in the virgin soil, about from $\frac{1}{3}$ to more than $\frac{1}{2}$ of the salt in the water extraction was $CaSO_4$.

Positions of Salts in Soil

In the virgin, difficult permeable, silt soils the maximum salts concentrations were usually found in the third, fourth, or fifth foot, more frequently in the fourth foot. In readily permeable silt soils, the highest concentrations were found most frequently in the fifth foot, while in sandy soils the sixth foot usually contained more salts than did the soils nearer the surface. Where the soils were irrigated, there was a movement of salts downward as the irrigation water soaked to greater depths than the rainfall had been able to penetrate. This loss of salts out of the top six feet of soil with two years of irrigation is shown graphically in Figures 1 and 2 and the amount, and kind of salts present in each foot of soil is presented in Table 1.

The amount and position of salts in three virgin soils is indicated in Figure 3, and the kinds and amounts of these salts are recorded in Table 2.

Tolerance of Crops for Salts

Where pure salts were added to a fertile soil practically free of alkali salts the germination of wheat and barley was slightly depressed with the addition of 0.5% of $NaSO_4$, 0.4% to 0.5% of NaCl, and 0.3% to 0.4% of Na_2CO_3. $MgSO_4$ seemed to have no depressing effect on the germination

TABLE 1.—CHANGE IN WATER SOLUBLE SALTS IN FIELD SOILS IN TWO YEARS

Depth, feet	Ions							Combinations								
	Ca	Mg	CO_3	HCO_3	Cl	SO_4	NN*	T.S.S..	$CaCO_3$	$Ca(HCO_3)_2$	$CaSO_4$	$Mg(HCO_3)_2$	$MgSO_4$	$NaHCO_3$	NaCl	Na_2SO_4	$NaNO_3$
Alfalfa field, 1917																	
1st	0.03	0.03		0.19	0.003	0.22	0.003	0.33		0.11		0.09		0.04	0.005	0.04	0.02
2nd	.07	.03		.12	.001	.31	.0009	.61		.16	0.09		0.17		.002	.16	.006
3rd	.49	.10		.07	.007	1.82	.0006	2.81		.09	1.60		.51		.01	.45	.004
4th	.49	.13		.06	.009	1.96	.0007	3.00		.08	1.61		.63		.01	.51	.004
5th	.39	.12		.05	.01	1.79	.0005	2.73		.06	1.29		.57		.02	.67	.003
6th	.27	.08		.05	.007	1.28	.0005	1.98		.06	.86		.40		.01	.56	.004
Alfalfa field, 1919																	
1st	.04			.07	.004			.38		.06					.006		
2nd	.04	.01		.06	.005	.07		.36		.08	.06		.05		.008		
3rd	.08	.03		.04	.008	.36		.71		.06	.22		.15		.01	.15	
4th	.48	.09		.03	.007	1.66		2.68		.05	1.59		.42		.01	.29	
5th	.37	.09		.03	.006	1.46		2.33		.05	1.23		.43		.01	.37	
6th	.22	.07		.04	.01	1.14		1.75		.05	.71		.36		.02	.53	
Mixed pasture, 1917																	
1st	.05	.02		.19	.003	.03	.002	.47		.21		.04	.04		.005		.01
2nd	.06	.02	.02	.13	.004	.17	.002	.53	.03	.17	.03		.10		.007	.11	.01
3rd	.31	.13	.008	.07	.009	1.48	.0007	2.37	.01	.09	.99		.63		.01	.44	.004
4th	.45	.09	Trace	.07	.01	1.67	.001	2.64	Trace	.09	1.47		.45		.02	.42	.008
5th	.31	.08	Trace	.07	.01	1.31	.001	2.11	Trace	.09	.96		.38		.02	.50	.009
6th	.29	.07		.06	.01	1.24	.001	1.98		.08	.91		.34		.02	.39	.008
Mixed pasture, 1919																	
1st	.03	.009		.09	Trace	Trace		.19									
2nd	.07	.02		.07	Trace	.27		.47									
3rd	.17	.05		.05	Trace	.71		1.14		.07	.63		.25		Trace	.04	
4th	.14	.04		.04	.005	.68		1.10		.05	.45		.22		.008	.29	
5th	.21	.06		.04	.01	1.00		1.56		.05	.69		.31		.02	.40	
6th	.13	.05		.04	.008	.95		1.23		.05	.42		.25		.01	.68	

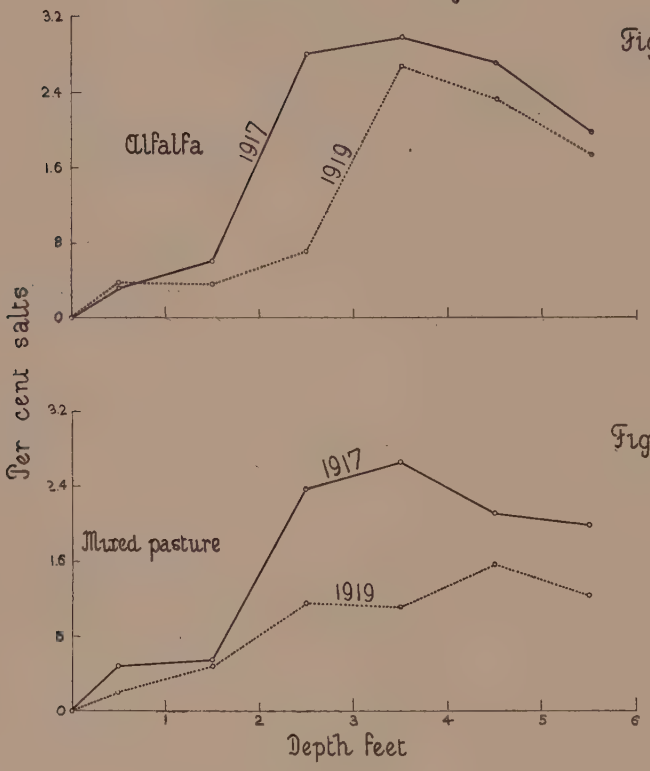
*Nitric nitrogen. †Total soluble salts.

TABLE 2.—WATER SOLUBLE SALTS IN TOP SIX FEET OF SOIL, TILLEY—RESULTS EXPRESSED AS PER CENT

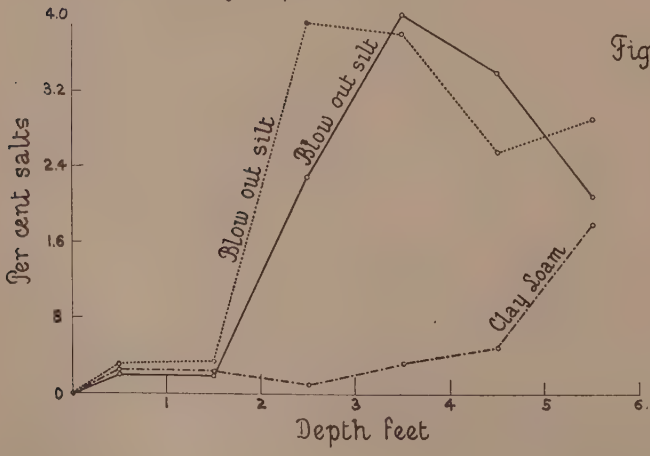
Depth, feet	Ions							Combinations								
	Ca	Mg	CO_3	HCO_3	Cl	SO_4	NN*	T.S.S.**	$CaCO_3$	$Ca(HCO_3)_2$	$CaSO_4$	$Mg(HCO_3)_2$	$MgSO_4$	$NaHCO_3$	NaCl	Na_2SO_4	$NaNO_3$
Blow-out silt																	
1st	0.02	0.009		0.09		0.01	0.002	0.20		0.07		0.04	0.01			0.002	0.01
2nd	.01	.007	0.008	.10	.001	.03	.0005	.19	0.01	.07		.03		0.05	0.002	.04	.003
3rd	.42	.08		.05	.01	1.47	.0003	2.30		.06	1.36		.38		.02	.31	.002
4th	.70	.12		.04	.02	2.54	.0003	4.01		.05	2.33		.61		.04	.78	.002
5th	.47	.08		.04	.01	2.09	.0004	3.36		.05	1.57		.39		.02	1.02	.002
6th	.20	.11		.03	.02	.13	.0006	2.12		.04	.65		.55		.04	1.13	.004
Blow-out Silt																	
1st	.02	.01	.008	.11	.001	.03	.0003	.31	.01	.07		.06		.001	.002	.02	.02
2nd	.05	.02		.08	.009	.15	.0008	.33		.11	.09		.10		.01	.02	.005
3rd	.72	.16		.05	.03	2.57	.0006	3.93		.06	2.38		.78		.05	.41	.004
4th	.49	.19		.04	.03	2.42	.0006	3.80		.05	1.62		.92		.05	.84	.004
5th	.22	.14		.05	.03	1.66	.0008	2.56		.07	.68		.67		.05	1.00	.005
6th	.18	.15		.05	.05	1.89	.001	2.92		.07	.57		.75		.07	1.38	.009
Clay loam																	
1st	.03	.01		.12	.004	.01	.004	.26		.14		.02	.01		.007		.02
2nd	.05	.009		.09	.001	.06	.008	.24		.12	.05		.03		.002		.005
3rd	.02	.009		.10	.001	.03	.0007	.11		.09		.03	.02		.002	.02	.004
4th	.07	.01		.10	.002	.14	.0005	.33		.13	.12		.05		.004	.03	.003
5th	.06	.02		.08	.007	.27	.0003	.47		.11	.10		.10		.01	.18	.002
6th	.35	.06		.07	.009	1.18	.0004	1.77		.77	1.12		.30		.01	.24	.002

*Nitric nitrogen. †Total soluble salts.

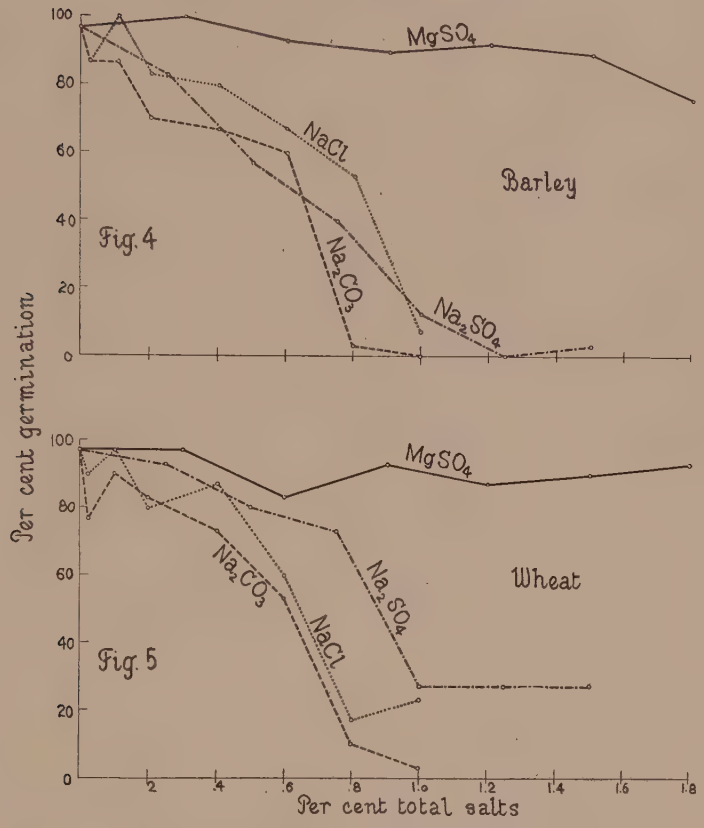
Change in total soluble salts in field soil in two years.



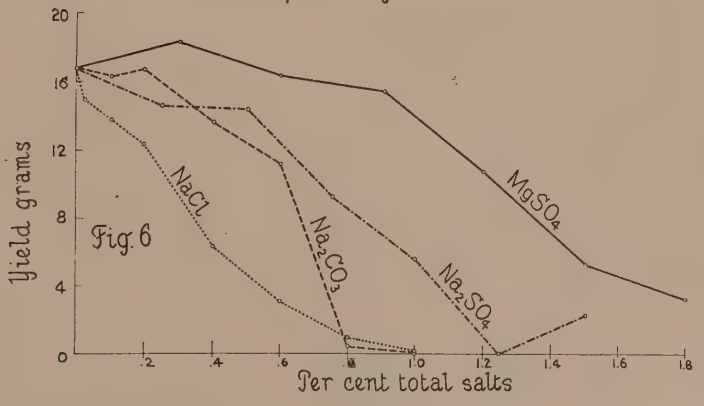
Amount and position of salts in virgin prairie soils



Germination of grain in soils containing various percentages of salts.



Yield of barley in soils containing various percentages of salts.



of wheat or barley when added to form a concentration of as high as 1.8%. Growth of the crops after emergence seemed to have been slightly influenced by about 0.75% to 1% of $NaSo_4$, 1% to 1.5% of $MgSO_4$, 0.3% to 0.4% of Na_2CO_3 or 0.1% to 0.2% of NaCl. $CaSO_4$ used alone had no apparent influence on germination and growth up to the maximum concentration used, which was 25% of the weight of the soil. This test with $CaSO_4$ was made in each of the years of 1918 and 1919 and in none of the individual pots was there any deleterious influence noted from the addition of gypsum to the soil. These results are in agreement with field experience on gypsum soils of the west where soils high in $CaSO_4$ are good agricultural soils.

Where mixtures of salts were used the addition of Na_2CO_3 or NaCl to a soil containing $NaSO_4$ did not appear to injure the crop unless enough of one of these salts was added so that it alone would cause injury indicating that the toxicity of these salts was not added to that of $NaSO_4$. The same condition seemed to prevail in a mixture of Na_2CO_3 and NaCl but not in a mixture of $NaSO_4$ and $MgSO_4$, although the harmfulness of a mixture of these two sulphates did not seem to be equal to the sum of the toxicity of each salt. For example, if the lethal point for Na_2SO_4 was 1% and for $MgSO_4$ was 1.5% then for a mixture of equal parts of the two it should

TABLE 3.—GERMINATION AND YIELD OF BARLEY ON SOIL CONTAINING VARYING AMOUNTS OF SALTS

Kind of salts	Per cent salt	Per cent germination	No. of plants	Grain straw, grams
Na_2SO_4	0	97	8	16.76
	.25	83	8	14.60
	.50	57	6	14.38
	.75	40	4	9.18
	1.00	13	1	5.55
	1.25	0	0	0
	1.50	3	0	2.17
$MgSO_4$	0	97	8	16.76
	.30	100	10	18.33
	.60	93	9	16.40
	.90	90	9	15.42
	1.20	93	9	10.68
	1.50	90	8	5.23
	1.80	76	7	3.20
Na_2CO_3	0	97	8	16.76
	.025	87	9	15.08
	.10	87	9	16.30
	.20	70	7	16.65
	.40	67	6	13.63
	.60	60	5	11.05
	.80	3	0	.37
	1.00	0	0	0
NaCl	0	97	8	16.76
	.025	87	9	14.98
	.10	100	10	13.75
	.20	83	8	12.33
	.40	80	8	6.35
	.60	67	6	3.00
	.80	53	4	.93
	1.00	7	1	.07

have been 1.25% if the toxic action of the two were added to each other. In the tests, however, it required 1.5% of the mixed salts to give the same harmful action as 1% of Na_2SO_4 or 1.5% of $MgSO_4$.

Crops were injured by a much lower percentage of salts as shown by analysis of alkali soils than where similar mixtures of pure salts were added to fertile soils. In field alkali soils it appeared that 0.7% to 1.2% of a mixture of approximately equal parts of sodium and magnesium sulphates was as injurious in a silt-loam as 1.5% to 1.7% of these salts added to a fertile soil of similar texture. There was a good growth of western rye grass in the presence of a mixture of 1.26% of sodium and magnesium sulphate on a medium clay loam. Crops were decidedly poor in the presence of 0.2% Na_2CO_3 in a sandy soil, and showed some signs of distress in the presence of as low as 0.05% of this salt when present in the first or second foot of soil. In the presence of sulphate salts or carbonates, the order of tolerance of crops after the plants were established seemed to be: western rye grass, brome, Kentucky blue grass, meadow fescue and Alsike clover. Peas germinated better than most crops but usually died in soils containing a high salts content when approaching the flowering stage. Flax was quite susceptible to alkali injury. Barley appeared slightly more tolerant than wheat after germination but the germinations of the two were quite similarly affected.

TABLE 4.—GERMINATION AND YIELD OF WHEAT ON SOIL CONTAINING VARYING AMOUNTS OF SALTS

Kind of salts	Per cent salt	Per cent germination	No. of plants	Grain straw, grams
Na_2SO_4	0	97	10	4.23
	.25	93	87	5.83
	.50	80	77	4.42
	.75	73	73	7.93
	1.00	27	3	4.35
	1.25	27	2	2.30
	1.50	27	3	4.15
$MgSO_4$	0	97	10	4.23
	.30	97	87	6.30
	.60	83	77	4.42
	.90	93	87	5.02
	1.20	87	80	5.83
	1.50	90	80	4.18
	1.80	93	87	2.52
Na_2CO_3	0	97	10	4.23
	.025	77	8	4.42
	.10	90	9	5.50
	.20	83	8	4.62
	.40	73	7	4.55
	.60	53	5	5.97
	.80	10	0	0
	1.00	3	0	0
NaCl	0	97	10	4.23
	.025	90	8	3.80
	.10	97	9	3.91
	.20	80	7	3.42
	.40	87	9	4.10
	.60	60	5	1.73
	.80	17	2	.18
	1.00	23	2	.27

Ameliorating Influence of $CaSO_4$

When gypsum was applied in connection with sodium and magnesium sulphate, it showed a very definite ameliorating action on the harmfulness of these white alkali salts. Almost normal growth of both barley and wheat was secured with a mixture of 2.5% of equal parts of sodium and magnesium sulphate where 2% of gypsum was added, while this concentration of these salts completely prevented germination where no gypsum was present. This beneficial action of gypsum was decided in all the replications of the experiments and while it had not been recognized by many soil chemists at the time these experiments were made, the modifying action of one ion in solution upon the harmfulness of another has been frequently observed since that time. A discussion of this interesting phase of the alkali problem will not be entered into here but its importance should not be overlooked by those who are working with soils having a high gypsum content.

TABLE 5.—THE AMELIORATING INFLUENCE OF GYPSUM ON THE TOXICITY OF EQUAL PARTS OF SODIUM AND MAGNESIUM SULPHATES ADDED TO SOILS AS INDICATED BY THE GERMINATION AND YIELD OF WHEAT AND BARLEY

Per cent of Na_2SO_4 and $MgSO_4$	Per cent of $CaSO_4$	Germination		Yield	
		Wheat, %	Barley, %	Wheat, grams	Barley, grams
0.0	0.0	97	90	4.23	16.09
0.5	0.0	93	93	5.05	16.48
0.5	0.5	73	90	3.38	19.30
0.5	1.0	90	83	4.85	16.65
0.5	2.0	70	93	3.23	18.65
1.5	0.0	73	80	2.42	10.50
1.5	0.5	70	57	2.93	7.40
1.5	1.0	70	80	3.08	7.20
1.5	2.0	87	83	2.78	5.53
2.5	0.0	0	0	0.0	0.0
2.5	0.5	0	0	0.0	0.0
2.5	1.0	13	13	5.22	6.07
2.5	2.0	80	83	4.28	13.55

SUMMARY

1. Alkali salts in the heavy soils of the Tilley, Alberta area are composed almost entirely of sodium and magnesium sulphates with considerable quantities of calcium sulphate.

2. The greatest concentrations of salts in virgin soils of low permeability were in the third or fourth foot while in more permeable soils the greatest concentrations were in lower depths. There was a definite leaching downward of the salts with irrigation.

3. Sodium sulphate was much more injurious than magnesium sulphate in these soils. When more than one salt was added to the soil the toxicity of NaCl or Na_2CO_3 did not appear to be added to that of Na_2SO_4, but this was not true of Na_2SO_4 and $MgSO_4$.

4. Calcium sulphate added to soil in large amounts did not decrease germination nor yields of wheat and barley, but where used in connection with Na_2SO_4 and $MgSO_4$ it definitely decreased the harmfulness of these salts.

SOME COMMENTS ON SOIL SURVEYING IN CANADA[1]

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The history of soil surveying in Canada is a comparatively short one. The first attempt at mapping soils in this country was made by the Topographical Survey of the Dominion Department of the Interior in 1919. Two years later soil surveying was started in and by the Provinces of Alberta and Saskatchewan. In the succeeding years most of the provinces entered this field of work until at the present time, seven of the nine provinces are carrying on soil surveys. The Topographical Survey, greatly curtailed their activities in 1925 and finally withdrew entirely from this work in 1930.

With the exception of the mapping done by the Topographical Survey, soil surveys have always been under the direct control of the provinces, the work being conducted either by the colleges or the Departments of Agriculture. The Federal Government, however, did not lose interest in this field with the cessation of activities by the Topographical Survey, as through the Dominion Department of Agriculture, financial aid has been given to the provinces for the encouragement of soil surveys. However this Department has never assumed any direct responsibility for the field work nor the manner in which the data was presented on the maps.

The organization of soil surveys in Canada is, therefore, such that there are at the present time seven distinct bodies in charge of this work, each of which receives financial assistance from the Dominion as well as from the Provincial Governments. Except for such voluntary co-operation as is possible, no provisions have been made for keeping these bodies in contact with each other.

While this setup has the merit of placing the direct responsibility of soil surveying in the hands of the men who are the most familiar with the soils and soil problems of each province, it has resulted in a lack of uniformity in the systems of soil classification in use, in the kind and amount of information relative to soils that is obtained and in the manner in which the data is presented on the soil map. Considering each province as a separate and distinct unit the soil survey methods in use have given good results but when each province is considered as only a part of the whole country, the results are not entirely satisfactory. The differences in the methods of soil classification, even though many of these differences are more apparent than real, and the various ways in which the soil maps are prepared, detract from the value of the work and constitute a limiting factor in use of the soil maps to the fullest advantage. Soil maps are not the easiest kind of maps to understand and the more the maps can be standardized the greater will be their value to the men who are interested in the soils in the different parts of this country.

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[1] Read before a meeting of the Soils Group of the C.S.T.A. at the University of Saskatchewan, Saskatoon, Canada, June 28 to 30, 1937.

[2] Soils Specialist, Division of Field Husbandry.

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The systems of soil classification that are being used in Canada are those that seemed to best fit local conditions and needs. Each individual in charge of soil surveys necessarily looked upon classification from the standpoint of his own experience and consequently several different systems of soil classification have emerged. The soils surveyors cannot be criticized for not developing a uniform system applicable to all the provinces for to do this it would be necessary to see all the soils in their natural habitat which requires time, travel, and resources, and such facilities were not available to them. Even within each province, the same system of soil classification could not always be adhered to for as the soil surveyor progressed in his work different soil conditions were encountered which sometimes necessitated a change or modification from the original scheme. In fact, soil surveying in this country is still in a state of flux.

With the knowledge that the soils men now have of the nature of the soils in Canada, a uniform system of soil classification that would be applicable to all the provinces could probably be devised without any great difficulty. However, the wisdom of adopting such a system of soil classification for the reconnaissance type of survey is open to question, for it is more important that the surveys within a province be uniform than that there should be uniformity between the provinces. However, in regard to such details as stoniness, textures, and topography, uniformity could be attained without disturbing the classification scheme in use.

There are other types of soil surveys, however, where a uniform system could be used, particularly in those provinces where the soils and the problems in connection with them are similar. Examples of such surveys are the detailed mapping of problem areas and the preparation of maps based on the reconnaissance soil survey which will more clearly interpret to the layman the practical significance of the different types of soil.

Even though it may be impractical to adopt a uniform classification for the reconnaissance surveys, the soil maps based on such surveys could be greatly improved if more uniformity was attained in their preparation. Some of the differences that can be observed in the present soil maps are in regard to the scale of mapping, the amount and kind of information concerning the soils, the use of symbols, and the colours used to denote the different soils. Of these, the last probably gives rise to the most confusion.

The most obvious feature of any soil map is the colour scheme which is used to show the location of the different soils. When any particular soil map is studied each colour becomes associated in the reader's mind with a particular type of soil. But unfortunately, this association, which has taken some time to learn, is not applicable to the maps from other provinces, as each province uses a different colour scheme. It can be readily understood that this lack of standardization adds to the difficulties in reading soil maps. This, particularly, is the case when adjoining soil maps from two provinces are being examined, where similar soils occur on both sides of the border.

Owing to the number of soil types in this country, and even in any one province, it would be impossible to allot a colour for each type of soil. However, soil surveyors should be able to attain at least some degree of a standardization on this matter without any great difficulty. One scheme

would be to use a certain range of closely related colours for heavy soils, another for light soils and another one for the intermediate soils. Soils such as peats and mucks, alkali soils, and soils with a well developed solonetz structure, could be allotted distinct colours. From the agriculturists' viewpoint these are the most important divisions within the broader categories which are usually of such size as to enable their separation to be made with solid or dotted lines.

Many problems must be solved by the soil surveyors in the different provinces before their work reaches the degree of uniformity that would seem to be desirable. I realize that owing to the distances between them that close co-operation is difficult to attain but any joint effort that the soil surveyors can make in standardizing their work would be well worthwhile.

THE APPLICATION OF SOIL CONSERVATION SURVEYS TO SOIL CONSERVATION PRACTICE IN THE UNITED STATES[1]

A. H. JOEL[2]
United States Soil Conservation Service

Assuming that most of those present are not very familiar with the organization and objectives of the U.S. Soil Conservation Service, I should like first to deal briefly with these matters. This, I believe, will serve as a useful foundation for developing the subject suggested to your program committee, namely, "The Application of Soil Conservation Surveys to Soil Conservation Practice in the United States."

The Soil Conservation Service is a regular bureau of the United States Department of Agriculture and is organized on a civil service basis. As its name indicates, the Service is primarily concerned with the conservation of soil; and, as soil losses are caused largely by accelerated erosion, the Service has always given special attention to the control and prevention of erosion. And, as erosion control is closely related to flood control, grazing control, irrigation practice, moisture conservation and other fields, this aspect of our work has broadened considerably.

In the set up of the organization there are divisions dealing with conservation and watershed surveys, conservation operations, co-operative relations and planning, research, personnel and training, and business management. In the Division of Research are branches engaged in climatic and physiographic investigations, sedimentation and river hydraulic investigations, erosion and farm economics, erosion investigations, watershed and hydrologic studies and hill culture. In the Division of Conservation Operations are branches dealing with agronomy, erosion control practices, engineering, woodland management, nurseries and wildlife management. In the Division of Co-operative Relations and Planning are branches dealing with information, co-operative planning and co-operative relations in extension. Dr. H. H. Bennett has been Chief of the Service since the time of its inception.

Much of both the administrative and technical work has been decentralized by organizing the United States into eleven regions, each with a regional office with units of organization generally corresponding to those in the Washington headquarters. Each region is headed by a Regional Conservator who is responsible for all the demonstration projects and associated Civilian Conservation Corps work camps. A special official is appointed for each state, known as a State Co-ordinator, whose duty is to co-ordinate the work of the Service with the state authorities and with other federal agencies working within the state.

There is a very interesting feature in the organization of our Service which has given it considerable strength and which has served to maintain a high tenor of enthusiasm among its personnel. I refer to the provision

[1] Read before a meeting of the Soils Group of the C.S.T.A. at the University of Saskatchewan, Saskatoon, Canada, June 28 to 30, 1937.

[2] Senior Soil Scientist, in charge of Western Field Office, Section of Conservation Surveys, U.S. Soil Conservation Service.

whereby in Washington, in the Regional headquarters and in the demonstration projects, there are included on the staffs a variety of agricultural technicians whose technical advice is ordinarily needed to solve the problems which most projects have to meet in their efforts to control erosion and to properly readjust land use. Most projects have soil specialists, agricultural engineers, agronomists, specialists in erosion control practices, and specialists in education and information. Where needed, there are also specialists in forestry, range management, wildlife management, and in other fields as needed for special situations. This permits the constant pooling and application of a wide range of technical agricultural knowledge to specific problems on individual farms or ranches and in particular project areas. It is felt that the problems are too complex for one specialist to solve alone.

In the drive toward its objective of conservation of soil and desirable land use readjustment, the Service has, since its organization, worked toward this end on the basis of demonstration projects. The program of these demonstration projects is based on the development of integrated land use in which the farms selected are all located upon one major watershed. The integrated land use that is promoted over the watershed is intended to give as near complete control of erosion and floods as is feasible and practical. It is also intended to develop systems of land use that are adapted to the physical requirements of the region and that are economically sound and adequately stable.

It is hoped that the practices developed and demonstrated on the projects will be adopted by neighboring farmers as well as by farmers operating under similar conditions but located at considerable distances away from the project. Hundreds of projects and associated work camps have been initiated in the United States. Some have been conducted for a long enough period to complete the physical phases of the work and have been placed on a maintenance basis.

The operations on individual farms are conducted under five-year co-operative agreements. These are legal contracts between farmers and the Government, in which each party agrees to certain contributions in the way of technical advice, materials, labour, surveys, farm adjustments, etc. By adjustments I refer to changes which the farmer agrees to make in his farming plans and operations, such as taking certain lands out of cultivation, changing cropping systems, changing fences, reducing the number of livestock on a given piece of pasture land, etc.

The conservation survey is the initial step in preparing for the work programs, and is the foundation for most of the erosion control and farm readjustment operations. It is made before the agreements are drawn up and the work plans formulated.

The conservation surveys are made according to a standard handbook supplied to all field men, entitled *Procedure for Making Soil Conservation Surveys*. Where available, air photographs are highly favoured as base maps, especially for detailed surveys. A scale of eight inches to the mile has been used on the majority of projects on farm land. On range land scales of two to four inches per mile have been more popular.

In the standard conservation survey four factors are mapped, namely, character and degree of erosion, land use or cover, per cent and class of

slope, and soil. These are indicated in a four point fractional symbol as follows:

$$\frac{\text{Erosion}}{\text{Slope}} \quad \frac{\text{Land Use or Cover}}{\text{Soil}}$$

Standard symbols are used for each intensity of each factor indicated. Numbers, letters and special symbols are used for this purpose.

A new boundary is drawn when there is a significant change in any single factor, and the full quadruple symbol is shown for each area delineated.

Sheet erosion is indicated by numbers to represent varying degrees, based on the percentages of the various soil horizons removed.

Gully erosion is also indicated by numbers, to indicate frequencies and by special symbols to show relative depth and relative susceptibility to further deepening.

Wind erosion conditions are indicated by letters to express varying degrees of removal and deposition.

Special symbols are also used to indicate stabilization of erosion, either complete or partial.

Land use is indicated by letters under the categories of cultivated, idle or abandoned, forested and pasture land.

Slopes are expressed in groups in relation to the possibilities of controlling erosion according to the more common types of land use. The average per cent of slope is also usually expressed.

Soils are mapped as soil types according to the system established and followed by the U.S. Bureau of Chemistry and Soils.

Although the conservation survey is a big job in itself, it is merely the start of the soil specialist's project duties. His really big job and his most important one is to apply this basic survey data or inventory of physical conditions to operations and project field practice. This involves a careful study and analysis of the data and its simplification and interpretation for the use of the agricultural engineer, agronomist, range specialist and other technicians. Usually, however, the survey data alone are inadequate to supply the operations technicians with the necessary information to work out a practical operations program. Additional information is usually needed. This is obtained by those engaged in research and also by what might be termed as service work or "quick tests" made by the soils men. These may include observations of simple soil moisture dynamics, soil reaction, dispersion and shrinkage behaviour of soil types, and plant-soil correlations.

As the surveys are completed and necessary supplementary information gathered, the combined data are analyzed and a program of erosion control and land use readjustment worked out by the various technicians working in close co-operation. The suggested plan is submitted to the farmer co-operator and when a plan agreeable to all concerned is finally adopted the co-operative agreement is drawn up and signed and the work program is started.

It requires little stretch of the imagination to realize how the survey and information gathered by the soils men may be usefully applied to operations. In fact, it requires a greater stretch of the imagination to figure out how such a program would be possible without these preliminary

data. The map showing the fourfold situation of soil, slope, erosion and land use is a basic picture of the land and its present utilization. A consideration of at least these four factors is necessary.

Two basic objectives of operations are to slow up the rate of flow of run-off water and to make the water sink into the ground at or near where it falls as precipitation. To accomplish this many areas of steep lands and severely eroded lands are retired from cultivation; vegetative cover is improved; various types of contour tillage and contour cropping are practised; water is diverted from critical places such as gullies or valuable lands subject to overwash or flooding; grazing is regulated; and various other methods with the same general objectives are followed. In addition, special measures are used to combat erosion damage by wind; for example, strip cropping, the use of stubble and crop residues, and the promotion of resistant types of soil structure.

In all of this work it is obvious that an accurate knowledge of soils, erosion, and related conditions, such as slope and vegetative cover, is necessary to work out the most practical and suitable program for correcting undesirable conditions prevailing in or threatening a given agricultural area. It should be equally obvious that such a program can be worked out only by the soils men and other technicians pooling their knowledge and viewpoints and working in close harmony toward a common end. The Soil Conservation Service has provided the opportunity for the various agricultural technicians to work in this manner in direct contact with the farmers and under actual field conditions. The Service is conducting a broad co-ordinated program over a wide range of conditions existing in the United States; and it will be highly interesting to study the various methods used and results obtained in this nation-wide battle to control erosion and to reorganize land use on a basis that is relatively permanent and economically sound.

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INTER-PLANT VARIATIONS IN CERTAIN SEED-SETTING PROCESSES IN ALFALFA

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INTRODUCTION

Alfalfa (*Medicago sativa* L. and related species with their various strains) has long been regarded as one of the most valued types of plant for forage purposes, but the uncertainty of satisfactory seed production, characteristic of alfalfa, has been a general problem of considerable economic importance. During the past 25 or 30 years many investigations bearing on this problem have been conducted under the diverse conditions of different geographical locations. Most of these investigations have been concerned with the seed-setting behaviour of plants in general under particular ecological conditions. Observations, however, at the University of Alberta at Edmonton, Canada, have indicated the existence of marked variations with respect to seed yields, and also the probability that these variations are relatively constant for the same plants year after year. It thus appeared that some progress with the solution of the problem of the causes of sterility or low seed-setting in alfalfa might be made by studying some of the floral processes involved in seed-setting and contrasting these processes, as observed in highly fertile plants, with those observed in sterile or very weakly fertile plants. The possibility of devising some method of determining seed-setting or fertility indices for individual plants was also to be kept in mind.

The extensive literature reporting investigations on the relation of seed-setting in alfalfa to ecological and certain other biological factors has been ably reviewed by Englebert (8), Armstrong and White (2), Torrsell (13) and others; hence a literature review need not be included here.

MATERIALS AND GENERAL METHODS

Plants of *Medicago sativa* L. were selected in two groups representing extremes of seed-setting capacity. From a population of over 2000 spaced plants consisting of various strains, many of which had been selfed for two or three generations, 20 plants which had been under observation for three or four years were chosen for experimentation. Nine of these plants had been rated as sterile or very weakly fertile, and the remainder were known to set seed abundantly under Edmonton conditions. The former plants are hereinafter designated "sterile" and the latter "fertile". These experimental plants are described in Table 1.

In October, 1934, the selected plants were transplanted from the field each into a glazed earthenware crock with a hole at the base for drainage and containing about one cubic foot of soil. After a dormancy period in a cool root cellar they were removed to a greenhouse at the end of December where optimum moisture conditions and a temperature of approximately 75° F. were maintained.

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TABLE 1.—DESCRIPTION OF THE EXPERIMENTAL PLANTS

Plant designation	Strain pedigree number	Origin of strain	Flower colour	Growth habit	Fertility classification
37-15s*	S_1.32.28	Grimm, Disco	Greenish yellow	Decumbent	"Sterile"
9-11s	S_1.28.3	Grimm, Grafton's	Yellow	Erect	"Sterile"
6-33s	S_3.33.9	Grimm, Lyman's	Light purple	Decumbent	"Sterile"
19-7 s	S_2.32.11	Grimm	White	Erect	"Sterile"
8-33s	S_3.33.10	Hansen's hybrid	White	Erect	"Sterile"
9-38s	S_2.32.5	Hansen's hybrid	White	Decumbent	"Sterile"
1-12s	S_3.33.1	Ontario variegated	Dark purple	Erect	"Sterile"
3-14s	S_3.33.2	Ontario variegated	Dark purple	Erect	"Sterile"
4-5 s	S_3.33.3	Ontario variegated	Dark purple	Erect	"Sterile"
8-28f	I·28·18	Grimm, Disco	Medium purple	Erect	"Fertile"
23-11f	S_1.31.1	Grimm, Disco	Light purple	Erect	"Fertile"
33-4 f	S_2.32.26	Grimm, Disco	Light purple	Erect	"Fertile"
34-5 f	S_2.32.26	Grimm, Disco	Light purple	Erect	"Fertile"
43-5 f	S_2.32.30	Grimm, Grafton's	Greenish yellow	Decumbent	"Fertile"
43-29f	S_2.32.30	Grimm, Grafton's	Light purple	Erect	"Fertile"
40-10f	S_2.32.29	Grimm, Lyman's	Light purple	Erect	"Fertile"
21-23f	I.31.9	Grimm	Light purple	Erect	"Fertile"
21-35f	I.31.9	Grimm	Light purple	Erect	"Fertile"
10-34f	S_2.32.7	Grimm, Kirk's	Light purple	Erect	"Fertile"
47-5 f	S_1.32.32	Cossack	Bluish	Erect	"Fertile"

* s and f signifiy "sterile" and "fertile" plants, respectively.

Artificial electric light was used to supplement the daylight each day until the middle of March.

On May 7, 1935, the plants were transplanted to the field where they were spaced four feet apart both ways. In order to guard against insect pollination during periods of experimentation a screen house was erected so as completely to enclose the stand of plants.

All flowers taken as samples were fully opened, but had not been unfolded more than three days. Whenever setting of pods or of seed was to be determined, or pollen-tube growth studied, the flowers were tripped artificially in order that the processes involved might not be inhibited by failure of the flowers to trip.

The killing and fixing solution used consisted of 6 cc. of formalin added to 10 cc. of 70% alcohol. Notwithstanding some possible disadvantages in subsequent staining of the material, this fixative proved to be very convenient, since numerous samples of flowers could be taken over long intervals of time and left in it until required for study.

EXPERIMENTS

Percentage of Pods Set

On each of the 20 experimental plants approximately 300 flowers were tested. One-third of these were tripped on July 29, 1935, and the remainder on August 9, eleven days later. After all the unopened flower buds and the flowers already tripped had been removed with forceps, the remaining flowers were tripped artificially, and each raceme was suitably tagged with the date and the number of flowers artificially tripped. The pods from both lots of artificially tripped flowers were harvested on September 5 and counted for each raceme. The number of pods was then expressed as a percentage of the number of flowers on the raceme, which had been artificially tripped. A summary of these data appears in Table 2.

TABLE 2.—NUMBER OF PODS SET PER RACEME EXPRESSED AS A PERCENTAGE OF FLOWERS TRIPPED

Plant designation	July 29		August 9		Both dates		G	H
	A* Number of racemes	B Mean percentage of pods per raceme	C Number of racemes	D Mean percentage of pods per raceme	E Number of racemes	F Mean percentage of pods per raceme	Difference between means for dates (D-B)	Difference as percentage of mean for first date
1-12s	16	0.00	27	0.00	43	0.00	0.00	
4-5 s	11	0.00	33	0.00	44	0.00	0.00	
3-14s	9	0.00	15	0.42	24	0.26	+ 0.42	
8-33s	9	0.00	28	0.89	37	0.68	+ 0.89	
19-7 s	6	2.72	12	1.16	18	1.68	− 1.56	
37-15s	14	1.02	23	3.03	37	2.27	+ 2.01	
6-33s	10	9.43	17	6.71	27	7.72	− 2.72	
9-38s	15	3.77	24	13.94	39	10.03	+10.17	
9-11s	15	7.73	28	13.78	43	11.67	+ 6.05	
40-10f	8	30.41	23	19.38	31	22.23	−11.03	−36.3
10-34f	8	30.05	21	22.94	29	24.90	− 7.11	−23.7
34-5 f	11	73.47	19	26.72	30	43.86	−46.75	−63.6
23-11f	6	61.67	16	43.88	22	48.73	−17.79	−28.8
21-35f	8	63.33	17	53.01	25	56.31	−10.32	−16.3
21-23f	11	90.06	18	35.81	29	56.37	−54.25	−60.2
43-5 f	12	52.36	23	67.01	35	61.99	+14.65	+27.9
8-28f	8	86.81	22	58.34	30	65.93	−28.47	−32.8
33-4 f	10	78.61	20	63.90	30	68.80	−14.71	−18.7
43-29f	9	64.22	15	71.59	24	68.83	+ 7.37	+11.5
47-5 f	8	85.68	18	82.32	26	83.35	− 3.36	− 3.9
								M = −22.3

* Columns of the tables are designated A, B, C, etc., for purposes of easy reference.

It is evident that the results of this experiment confirm the original classification of the plants into the "sterile" and "fertile" groups. However, the differentiation between the two groups is not as wide as might have been expected, since extremes were sought in the original selections. In some instances the variations between plants within a group are larger than variations between some plants in the different groups. It seems likely that the mean percentages of pods per raceme would have shown gradations from zero to a very high value had a large sample of plants been taken at random in the beginning of the experiment.

Column D of Table 2 discloses a general tendency for pod yields to be decidedly higher for flowers tripped on July 29 than for those tripped on August 9. It seems possible that the weather subsequent to tripping offers a partial explanation of the difference. On July 31, two days after tripping the first set of flowers, a steady rain continued for about 24 hours when 1.61 inches of rail fell. This was followed by 0.32 inches August 4; 1.08, August 13; 0.21, August 17; and frequent light showers thereafter for a few days. Such weather would be expected to provide very favourable soil moisture conditions for pod development. But the latter part of August was dry and hot, and, while favourable for automatic tripping, would not likely promote the development of pods. It has been reported by Alter (1) and Englebert (8) that rain following fertilization helps to increase the yields of seed.

Torssell (13) also found that seed-setting frequency declined markedly in August during the late stages of the flowering period. He thought the the decline was probably due to the poorer climatic conditions (higher humidity and lower temperature) which prevailed at that time. It would appear that Torssell's decline may have been due to climatic conditions unfavourable to tripping and fertilization, while ours was possibly due to conditions too dry to permit the development of pods after fertilization had taken place. It also seems possible, however, that in both cases the stage of seasonal plant development may have had some effect. Internal plant factors may not promote seed-setting as strongly in the late stages as in the early stages of the flowering period.

Although the general tendency was for higher yields following the first pollinations, this result did not obtain for all plants. Most cases of higher pod setting after the first pollination date were among the "fertile" plants. The variability in pod-setting is also greater among this group. This is probably to be explained by the fact that the "sterile" group set so few pods on either date, that differences in yield among these plants would be small even under optimum moisture conditions. It may be that the variability in the fertile group was partially due to the positions of the racemes on the plants. On the second date it was sometimes difficult to secure enough exposed flowers to make up the required two hundred, and occasionally racemes obscured in shaded portions of the plants had to be utilized. Thus differences in the degree of shading and consequent variations in temperature may have affected the set of pods to some extent.

The Number of Seeds per Pod

After the pods obtained in the previous experiment had been counted, they were decolorized in 70% alcohol. With the use of a strong transmitted light, the number of seeds in each pod was easily counted. Since the numbers of pods obtained from plants in the "sterile" group were not large enough to provide an adequate sample, they were not included in this study. A summary of data is presented in Table 3.

The results indicate that wide variations occurred between individual plants with respect to the number of seeds per pod. It is also evident that the number of seeds per pod, like the percentage of pods set, was reduced in most plants following the second series of pollinations. If the data in Table 3 are compared further with those given in Table 2, it will be noted that both gave approximately the same ranking of plants. This is perhaps to be expected. One may assume that factors tending to increase or decrease the percentage of pods set would have a similar effect on the number of seeds per pods, since both pod-setting and seed-setting are necessarily dependent on fertilization.

However, the fact that the two rankings are not quite the same is of some interest. This indicates that the plants varied in the relative degrees of their reaction, in so far as "percentage of pods set" and "seeds set per pod" were concerned, to the conditions associated with the two dates of tripping. It would seem, however, that more extensive data statistically analyzed would be required before any conclusion could be drawn regarding this point.

In general, there are marked average declines in "percentage of pods set" and "seeds set per pod" from the first date to the second. The average decline in the former is -22.3%, while that for the latter is -7.6%.

TABLE 3.—NUMBER OF SEEDS PER POD FOR THE "FERTILE" PLANTS

Plant designation	July 29		August 9		Both dates		G	H
	A Number of pods	B Mean number of seeds per pod	C Number of pods	D Mean number of seeds per pod	E Number of pods	F Mean number of seeds per pod	Difference between means for dates (D-B)	Difference as a percentage of value for first date
40-10f	32	1.56	47	1.62	79	1.60	+0.06	+ 3.8
23-11f	53	1.91	96	1.54	149	1.67	− .37	−19.4
10-34f	34	1.62	48	1.92	82	1.79	+ .30	+18.5
21-35f	73	1.93	112	1.84	185	1.88	− .09	− 4.7
34-5 f	83	2.21	54	1.96	137	2.11	− .25	−11.3
43-5 f	63	2.46	152	2.44	215	2.45	− .02	− .8
33-4 f	94	2.94	138	2.45	232	2.65	− .49	−16.7
43-29f	85	2.88	143	2.77	228	2.81	− .11	− 3.8
21-23f	100	3.32	68	2.60	168	3.03	− .72	−21.7
47-5 f	101	3.49	182	3.09	283	3.23	− .40	−11.5
8-28f	99	3.62	116	3.03	215	3.30	− .59	−16.3
								M = − 7.6

These values are comparable, since they are both on a percentage basis. They indicate that the change from the first date to the second is much more marked for "percentages of pods set" than for "seeds set per pod". It might possibly be inferred from this that "seeds set per pod" is less likely to be reduced by less favourable environmental conditions during and following pollination, than is the "percentage of pods set". Carlson (5) found that 75% only of the pods set survived until harvest time, 25% being lost probably as a result of unfavourable external conditions. The number of seeds per pod in those remaining would not likely be affected in the same way. Thus, if the number of seeds per pod remains relatively stable for different external conditions, it may be a more reliable index of inherent fertility than either the percentage of flowers represented by pods at harvest time or the total seed yield.

Pollen Viability

Pollen viability as determined by the percentage of pollen germinating on an artificial medium was tested as follows. After trying various concentrations of sugar, it was found that 12% cane sugar added to 1.5% agar-agar gave the best results. The medium was poured into a Syracuse dish, allowed to cool, and a sample of pollen from one plant was dusted upon it immediately. The dish was covered and kept at room temperature for two hours. It was then placed in a cooling chamber at about 0° C. until the germinated pollen could be counted. A few drops of a weak solution of methylene blue placed on the medium just before a count was made facilitated the counting. Since the amount of pollen per anther varied in different plants, no fixed number of flowers was used to obtain a sample. Usually from 5 to 10 were sufficient. One hundred counts were made from each dish using a low-power objective and 10× oculars. Only grains showing unmistakable evidence of germination were classified as viable. The number of pollen grains recorded from each sample ranged from 400 to 1400 varying with the different plants under test. The average was 1100 to 1200 per plant. Samples were taken March 26, 1935, while

the plants were in the greenhouse, and, to represent field conditions, a further set of samples was taken July 8, 1935, from the plants which had been transplanted into the field in the spring. Unfortunately a method of measuring the relative amounts of pollen produced by the different plants was not devised and comparative estimates only of these values are presented. A summary of the results is given in Table 4.

The variability among plants in pollen viability is striking. Values for plants in the "fertile" group are in general higher than those for plants in the "sterile" group. Plant 43-29f appears to be irregular in that it was originally classified as "fertile", but its percentage of viable pollen places it among the "sterile" group for this feature. It varied widely in viability between the two dates, and further checking would seem to be desirable.

TABLE 4.—PERCENTAGE OF POLLEN GERMINATION

Plant designation	Mean percentage germination				Comparative estimates of pollen amount
	A March 26 (greenhouse conditions)	B July 8 (field conditions)	C The two dates combined	D Difference between two dates	
3-14s	17.4	9.2	13.3	8.2	Very low
1-12s	28.8	27.0	27.9	1.8	Low
4-5 s	46.5	19.9	33.2	26.6	Low
9-38s	53.2	28.0	40.6	25.2	Low
6-33s	46.6	43.7	45.2	2.9	High
9-11s	56.0	43.1	49.6	12.9	Fairly high
43-29f	68.3	32.7	50.5	35.7	High
19-7 s	58.9	43.5	51.2	15.4	Fairly high
37-15s	69.3	58.7	64.0	10.7	Low
34-5 f	73.0	69.4	71.2	3.5	High
33-4 f	78.0	66.7	72.4	11.3	High
47-5 f	78.9	71.3	75.1	7.6	High
21-35f	77.8	74.8	76.3	3.1	High
10-34f	84.8	70.7	77.7	14.1	High
8-28f	85.3	76.0	80.6	9.3	High
21-23f	89.3	79.3	84.3	10.0	High
40-10f	89.6	79.2	84.4	10.4	High
23-11f	85.6	79.5	84.6	10.1	High
43-5 f	91.6	84.3	87.9	7.3	High

At first sight it might appear that some relation between percentage of viable pollen and percentage of pods set is indicated, but this is found not to be the case when correlations are calculated for mean "percentage of pods set per raceme" (Table 2, Column F) and "mean percentage of pollen germination" (Table 4, Column C). This applies equally for the "sterile" group, for the "fertile" group and for both "sterile" and "fertile" plants included in a single group. The coefficients of correlation for these groups are as follows:

Group	r	t	P
"Sterile"	+0.336	0.874	0.3+
"Fertile" plants	− .287	.899	.3+
"Sterile" and "fertile" plants	− .119	.494	.6+

These correlation coefficients are small, and in all cases must be regarded as insignificant in consideration of their high P values. The first three plants listed in Table 4, *viz.* 3-14s, 1-12s and 4-5s were low in pollen germination (under 35%), and at the same time set practically no pods, but otherwise the plants in the two groups behaved so irregularly that one is unable to establish any relation between percentage of viable pollen and percentage of pods set.

The plants producing pollen of low percentage viability also produced relatively small quantities of pollen. Perhaps the same causative factors were responsible for both these deficiencies.

It may be that percentages of pollen viability in excess of 40 or 50%, if the amount is fairly high, do not tend to increase the setting of pods. This suggestion is in harmony with conclusions of other investigators; Armstrong and White (2) state that pollen was usually abundant enough for fertilization in both high and low seed-setting plants of alfalfa, and Englebert (8) concluded that 22.5% of sterile pollen was unimportant if the total amount was large. Brink and Cooper (3) found that pollen abortion is not an important factor generally in alfalfa seed-setting.

The general decrease in pollen germination under field conditions as compared with greenhouse conditions (Table 4, Columns B and A respectively) is apparent. The decrease varied greatly for different plants. It is believed that these facts can be explained by regarding the non-germinating pollen as consisting of two types, one composed of the small clear grains which were studied by Clarke and Fryer (6) and found to remain constant for a given plant under wide environmental variations, and the other type composed of normal appearing grains which might have germinated had a more suitable medium been used, or which, on account of their high sensitivity, may have been adversely affected by unfavourable environmental conditions during development.

Pollen-tube Growth Within the Pistil

For this study material was collected from plants growing in the field at two different periods, one commencing on July 31 and the other on August 6. The procedure was to trip on each of these dates a sufficient number of flowers on each plant for the experiment. Lots of about 10 flowers were collected from each plant at successive intervals after tripping. The intervals for the first period were 2.5, 5, 8, 13, 19, 25, 31, 37, 43 and 49 hours; and for the second period, 3, 5, 7, 9, 12, 16, 20, 24, 27, 30, 33, 36, 40 and 48 hours. The varying conditions of atmospheric temperature and relative humidity were recorded for each period by means of a thermohygrograph.

Due to the hard tissue composing the outer part of the style, it was not possible to stain and crush fresh stylar material for microscopic examination. Accordingly, after collection, the material was immediately fixed in the formalin-alcohol solution mentioned previously. Later it was embeded in paraffin, sectioned, stained and mounted in Canada balsam.

Various stains were tried with dissatisfaction, possibly due to the killing solution, formalin-alcohol, which is not usually regarded as a good fixative to precede the use of the best stains. Acid fuchsin, however, was found to give good differentiation in the stigma and ovary, although it was seldom possible to trace pollen tubes within the central and lower

parts of the style. The following schedule for staining and mounting was devised:

1% aqueous acid fuchsin	1 to 2 hours
Distilled water	6 changes
70% alcohol	1 minute
95% alcohol	1 minute
Absolute alcohol	5 minutes

Clear in xylol and mount in Canada balsam.

It was necessary to use distilled water (pH 4.7) since tap water (pH 7.7) removed the stain in the water changes.

Because of the labor involved in the use of the paraffin method only three plants were studied. These differed widely in their seed-setting capacities. Plant 8-28f was one of the most fertile plants under study; 6-33s set a very low percentage of pods, and 1-12s set no pods.

The records of temperature and relative humidity are given in Figure 1, and a summary of the remaining data is given in tables 5 and 6. It should be mentioned that all numbers of pollen tubes given in the tables are minimum values, since it was often difficult or impossible to be sure of the total number present.

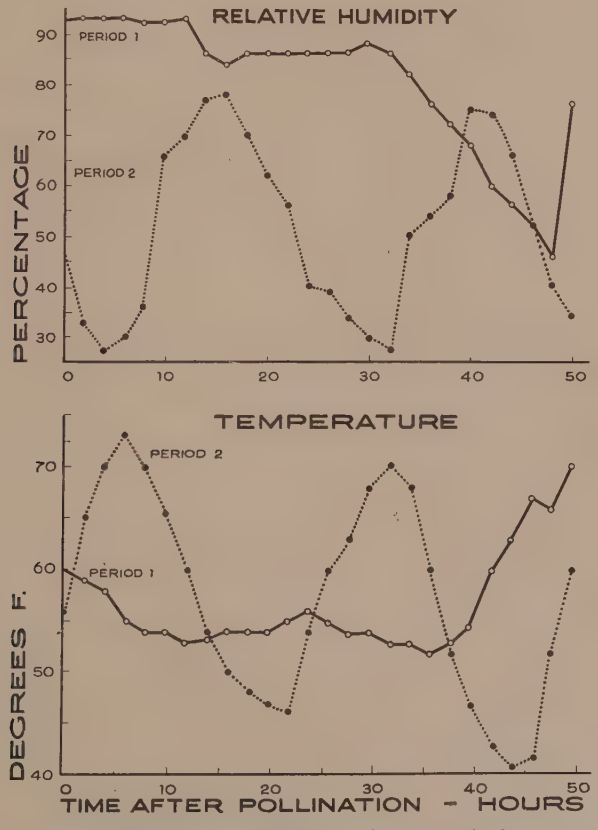

FIGURE 1. Temperature and relative humidity records for two periods during which samples were taken for the analysis of pollen-tube penetration into the stigma and ovary. Period 1 commenced at 4.30 p.m. July 31 and ended 5.30 p.m. August 2. Period 2 commenced at 8.30 a.m. August 6 and ended at 8.30 a.m. August 8.

For the data given in Table 5 only stigmas collected at the first four intervals for each period were used. The values for plant 8-28f are considerably higher than those for plant 6-33s, both in number of stigmas penetrated and in mean number of pollen tubes penetrating. These differences no doubt are largely responsible for the marked difference in fertility between these two plants (see Table 2). Values for plant 1-12s are very low and it would seem that the almost complete failure of the pollen to penetrate the stigmas is responsible for the entire failure of this plant to set pods. However, since there is some penetration, one might expect an occasional pod, at least, to be set (see Table 2).

TABLE 5.—SUMMARY OF DATA RELATING TO THE PENETRATION OF POLLEN TUBES INTO THE STIGMA

Plant designation	Total number of stigmas examined		Total number of stigmas penetrated		Total number of pollen tubes penetrating		Mean number of pollen tubes penetrating	
	July 31	August 6	July 31	August 6	July 31	August 6	July 31	August 6
8-28f	36	36	34	35	270	275	7.5	7.6
6-33s	36	36	28	32	90	178	2.5	4.9
1-12s	35	34	14	3	38	3	1.1	0.1

NOTE:—Mean values include stigmas which showed no evidence of penetration.

To secure the data presented in Table 4 the ovaries collected at each interval were examined and the numbers of pollen tubes present were noted. The differences in this case are relatively similar to, and serve to verify the data given for the penetration of pollen tubes into the stigma, (Table 5). Additional data were obtained on the rate of growth of pollen tubes as indicated by the time from tripping to ovary penetration. The variation in the time interval among the three plants is very marked for the July 31 date, and if the number of pollen tubes present at the interval when penetration was first noted is considered, there are also apparent differences for the August 6 data, particularly between plant 8-28f and the other two plants. These latter variations are probably not very significant, and it may be that under the more favourable atmospheric conditions prevailing at the August 6 date, the differences between plants in the rate of pollen-tube growth tended to lessen.

At this point it may perhaps be suggested that penetration of the ovary by the pollen tube may not necessarily result in immediate fertilization. Although the time at which fertilization occurred was not determined, it was observed that the ovary may be penetrated in the brief period of seven hours. Cooper (7) and Reeves (11) both found evidence of fertilization in alfalfa from 24 to 32 hours after pollination. Thus it appears that a delay may occur between penetration of the ovary by the pollen tube and fertilization of the ovule.

The most striking observation from the data in Tables 5 and 6 is the variation among the different plants. However, there are also differences within the same plant for the two date periods, particularly with respect to the time intervening between tripping and the first penetration of pollen

TABLE 6.—SUMMARY OF DATA RELATING TO THE PENETRATION OF POLLEN TUBES INTO THE OVARY

Plant designation	Total number of ovaries examined		Total number of ovaries penetrated		Total number of pollen tubes penetrating		Mean number of pollen tubes penetrating		Time of first penetration of pollen tubes into ovary		Number of pollen tubes present at time of first penetration into ovary	
	July 31	Aug. 6	July 31	Aug. 6	July 31	Aug. 6	July 31	Aug. 6	July 31	Aug. 6	July 31	Aug. 6
8-28f	74	113	67	112	314	445	4.2	3.9	8 hr.	7 hr.	1	30
6-33s	75	116	47	99	63	174	0.8	1.5	13 hr.	7 hr.	2	2
1-12s	73	112	25	9	35	10	0.5	0.1	25 hr.	9 hr.	5	1

NOTE:—Mean values include ovaries which showed no evidence of penetration.

tubes into the ovary. The difference in this respect between dates for plant 8-28f is only one hour which probably is not significant. The number of pollen tubes present for this plant at the time of the first penetration into the ovary was, however, greatly in excess for the second date over that for the first date. This would indicate a more rapid general pollen-tube growth on this plant for the second period than for the first. Apart from this, plant 8-28f appears to be relatively stable with respect to pollen-tube growth and stigma and ovary penetration under the very different climatic conditions on the two dates of tripping.

For plants 6-33s and 1-12s the differences in time of first penetration of pollen tubes into the ovary between the two dates are six and sixteen hours respectively (Table 6), the less time being required in the second date period for both these plants. These differences are undoubtedly due to differences in the rate of pollen germination and pollen-tube growth, which are probably referable to the different weather conditions immediately following tripping on the two dates. Tripping on the first date was done at 4.30 p.m., July 31, and was followed by two days of wet and cool weather, whereas tripping on the seeond date was done at 8.00 a.m. on August 6, and was followed by low atmospheric humidity and high temperature. Figure 1 indicates the humidity and temperature conditions immediately following tripping on both dates. During the first ten or twelve hours after tripping, when pollen germination and pollen-tube growth would normally take place, weather conditions as indicated by the graphs (Fig. 1) were just the opposite for the two dates.

It would seem, therefore, that, for the relatively non-fertile plants 6-33s and 1-12s at least, the more rapid pollen-tube growth for the second period was attributable either to the lower atmospheric humidity or to the higher temperature or to both. At the same time it seems likely that for these two plants the retarded rate of pollen-tube growth for the first period was attributable either to the higher atmospheric humidity or to the lower temperature or to both. Buchholtz and Blakeslee (4) found a steady increase in the rate of pollen-tube growth in *Datura stramonium* from 52° F. to a maximum at 92° F. Smith and Cochran (12) found 70° F. to 85° F. to be the optimum range of temperature for pollen-tube growth in the tomato. In view of these results it seems probable that temperatures

slightly over 70° F. may tend to accelerate pollen-tube growth in alfalfa, particularly in plants of low fertility as compared with temperatures of approximately 55° F.

It will be noted in Table 5 that plants 6-33s and 1-12s react oppositely for the two date periods, in that the average number of pollen tubes penetrating the stigmas of plant 1-12s was somewhat higher for the July 31 period, than for the August 6 period, while for plant 6-33s the reverse was the case. Perhaps the particular combinations of humidity and temperature conditions to which these plants were subjected during the two date periods may have been responsible for their opposite reactions. Martin (10) and Armstrong and White (2) have shown high atmospheric humidity to be favourable for pollen germination in alfalfa, and Smith and Cochran (12) have demonstrated that 85° F. was optimum for pollen germination in the tomato. Plant 6-33s was a decumbent plant, and it is probable that, at the time of the second pollination, a high humidity was maintained about the flowers on the decumbent branches, and this combined with the higher temperature prevailing at the second date of tripping was likely very favourable for pollen germination. On the other hand plant 1-12s was very erect in growth habit and, consequently, its flowers would be exposed to the more severe drying action of the sun and wind than would be the case with plant 6-33s. Thus, on plant 1-12s, the lower atmospheric humidity in the uppermost flowers at least, may have counteracted the favourable action of the high temperature.

DISCUSSION

This investigation was prompted by two interests in particular, *viz.*, a desire for a better understanding of the floral processes responsible for sterility in alfalfa, and the acquisition of information which might facilitate the development of high seed-setting strains in connection with alfalfa plant breeding projects.

Perhaps the most striking general result is the wide variability in fertility among alfalfa plants enacting seed-setting processes under approximately the same environmental conditions. This variability is evident in all the experiments of this investigation. It has been demonstrated that under varying conditions one plant may react differently, while another may tend to remain relatively stable. These results indicate the action of genetic factors favouring high seed-setting, which have been accumulated in particular plants. Consequently it is suggested by the authors that marked variations in seed production from year to year in a stand of alfalfa may be due, in some degree at least, to a large proportion of unstable individuals which require favourable external conditions in order to set seed freely. A further conclusion is that the few high-yielding plants usually present in poor years represent in such stands individuals so constituted genetically that they are less sensitive to a somewhat unfavourable environment, and are therefore capable of relatively high seed production even though environmental conditions deviate considerably from those optimum for seed-setting.

These studies indicate that the amount and viability of pollen and pollen-tube growth are important factors in contributing to wide differences in seed-setting capacity of plants and also to small gradations in fertility

between plants of the sterile group. When the amount of viable pollen is above a certain level, variations in this may possibly be disregarded as a cause of sterility, provided of course, it remains reasonably constant under varying environmental conditions. However, it appears that within certain limits no single variable feature of the pollen can wholly account for the extreme differences between "sterile" and "fertile" plants. It is also evident that in highly fertile plants these effects are relatively unimportant in differentiating small degrees of seed-setting ability.

A consideration of the temperature and humidity records in relation to the results indicates that in certain plants these weather factors may influence both pollen germination and the rate of pollen-tube penetration. This suggests that environmental factors may be very useful in the detection of unstable plants with constitutions unsuitable for the development by breeding of high seed-setting strains of alfalfa.

Some of the most fertile plants used in this investigation are the products of first and second generations of selfing, and although other workers have found a general decrease in seed yield from selfing, they have also reported plants which have maintained yield and vigour. Thus the results of selfing given by Kirk (9) show maintenance or increase of later generations over parental stock in both forage and seed yields. Similarly Tysdal and Clarke (14) report a selfing project in which seed yields of lines in the fourth generation exceeded those of the parent plants. It would seem, therefore, that selfing may unhesitatingly be included in a program of improvement of seed-setting capacity in alfalfa. Selfing would facilitate the analysis of stocks and progenies for morphological characters and for reproductive stability under the action of somewhat unfavourable environmental factors. It seems probable that combinations of desirable characters including stability of high seed-setting capacity might thus be attained. If growth vigour is reduced in the process, this loss could presumably be recovered by intercrossing of the selfed strains.

SUMMARY

1. Tripping of alfalfa flowers was found not to be the only limiting factor in fertility, since fertility differences between plants occurred after artificial tripping.

2. Marked differences in the number of seeds per pod were found between plants in the "fertile" group.

3. Evidence is presented to show that for "fertile" plants the number of seeds per pod may be a more reliable index of inherent seed-setting capacity than the percentage of flowers which give rise to fully developed pods.

4. When the two dates of tripping were compared, "percentage of pods set" and "mean number of seeds per pod" were lower for the second date. It is suggested that soil moisture and the stage of seasonal development of the plant may have contributed somewhat to these differences.

5. The test of pollen viability on an artificial medium gave wide variations between different plants and considerably higher germination was secured from greenhouse plants than from the same plants grown later in the field. The mean pollen viability (greenhouse and field results combined) ranged from 13.3 to 64.0% for "sterile" plants, and from 50.5 to 87.9% for "fertile" plants.

6. Two classes of sterile pollen were noted. One consisted of clear, empty-appearing grains and the other of apparently normal grains which did not germinate. It is suggested that the latter class may have been in reality viable, but that the particular conditions supplied did not induce the grains to germinate; or that the latter type of grains, being highly sensitive to environmental conditions were adversely affected thereby during the course of their development.

7. Relatively high temperature conditions apparently accelerated pollen-tube growth, though certain individual plants reacted somewhat differently in rates of pollen-tube growth under two different temperature conditions.

8. Penetration of the ovary by pollen tubes occurred within seven hours after tripping on August 6 in the case of two plants, while nine hours were required for a highly sterile plant.

9. It is suggested that an accumulation of genetic factors which contribute to fertility may tend to maintain the seed-setting stability of fertile plants even when the environmental conditions may be somewhat unfavourable.

10. It would seem that self-fertilization may be included in a program of improvement of seed-setting capacity in alfalfa.

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